Learning Objectives

- Define
  - Operations Management & Supply Chain

- Identify
  - Similarities & Differences across Products and Services
  - Functional areas of organization and their inter relation

- Explain & Summarize
  - Importance of learning O&SCM
  - Aspects of process management
  - Current issues
  - Need to manage

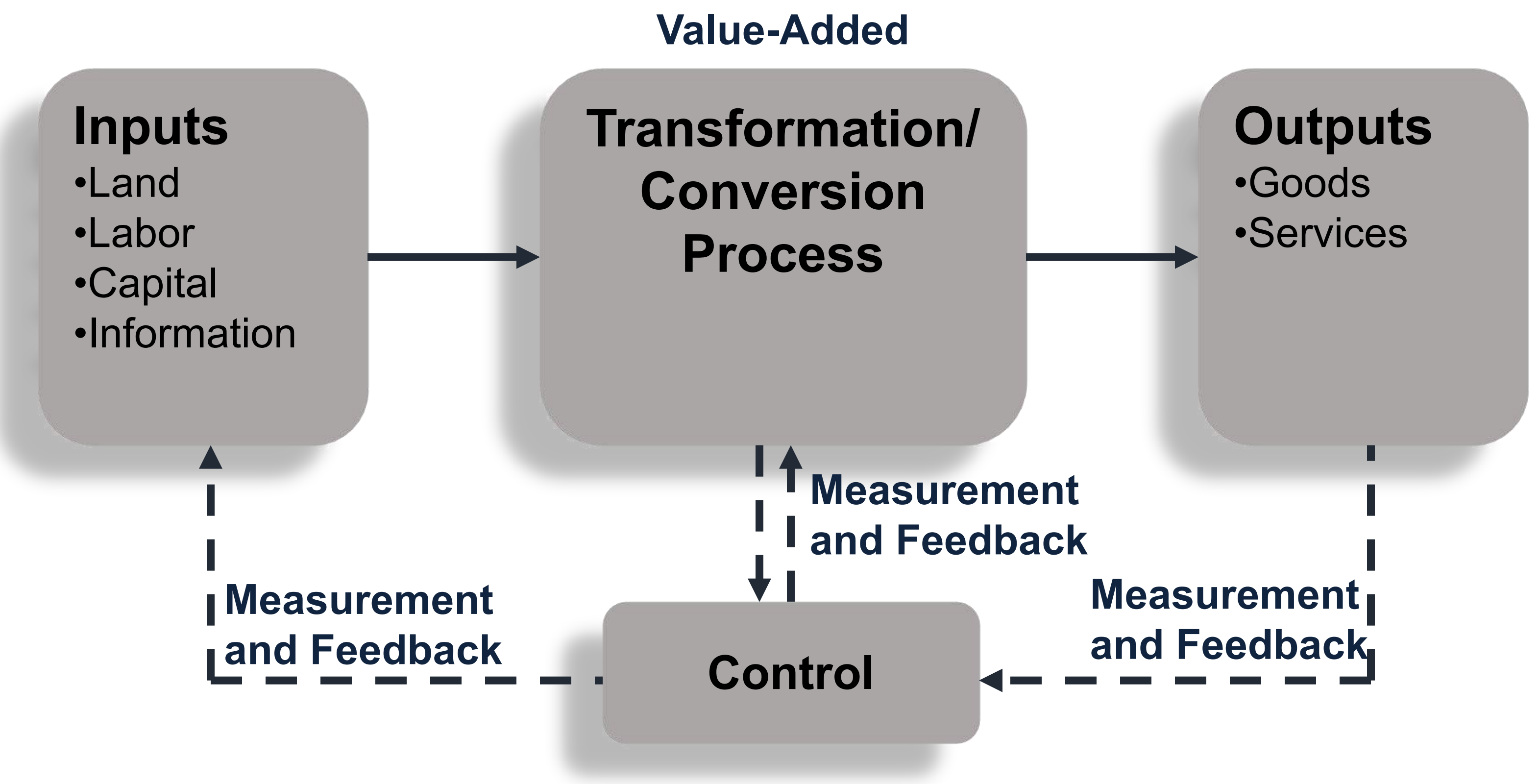
Background

- What are (business) organizations?

  Productive activity = F(Land, labour, capital, entrepreneurship)

- Why do they exist?

The Transformation Process



Feedback = measurements taken at various points in the transformation process

Control = The comparison of feedback against previously established standards to determine if corrective action is needed.

Transformation Process

- *Physical:* as in manufacturing operations
- *Locational:* as in transportation or warehouse operations
- *Exchange:* as in retail operations
- *Physiological:* as in health care
- *Psychological:* as in entertainment
- *Informational:* as in communication

Manufacturing vs. Service

Pick a few business organizations and ask:

1. Degree of customer contact
2. Uniformity of input
3. Labor content of jobs
4. Uniformity of output
5. Measurement of productivity
6. Production and delivery
7. Quality assurance
8. Amount of inventory
9. Evaluation of work
10. Ability to patent design

Good or Service?

Goods are physical items that include raw materials, parts, subassemblies, and final products.

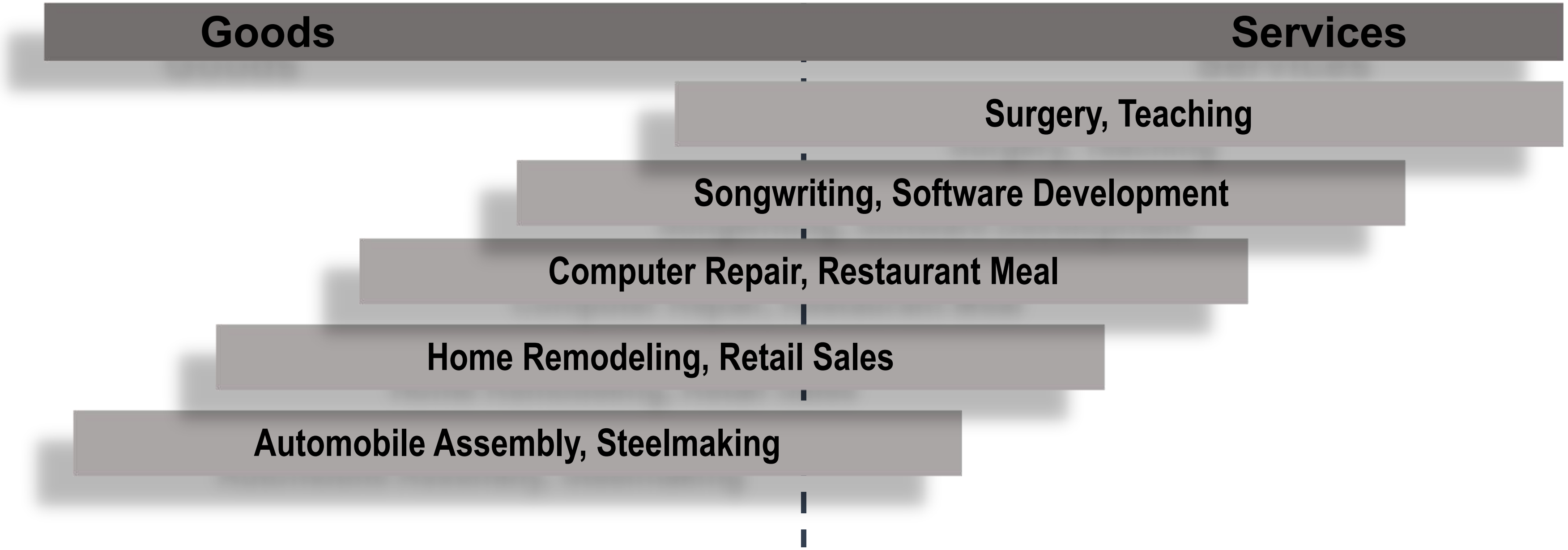
- Automobile
- Computer
- Oven
- Shampoo

Services are activities that provide some combination of time, location, form or psychological value.

- Air travel
- Education
- Haircut
- Legal counsel

Goods-service Continuum

Products are typically neither purely service- or purely goods-based.

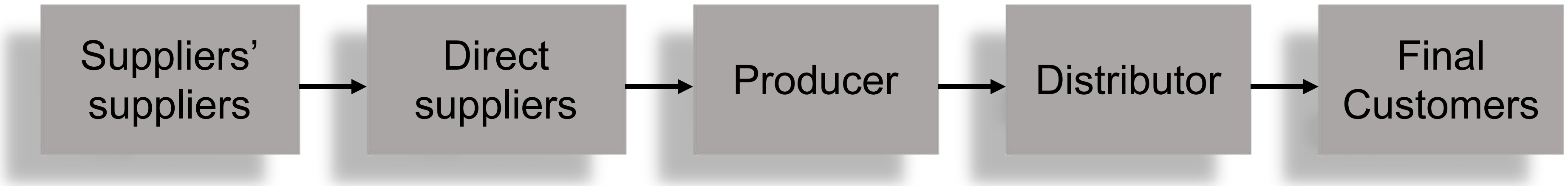


Operations Management

- What is operations?
  - The part of a *business organization* that is responsible for producing goods or services
- How can we define operations management?
  - The management of systems or processes that create goods and/or provide services

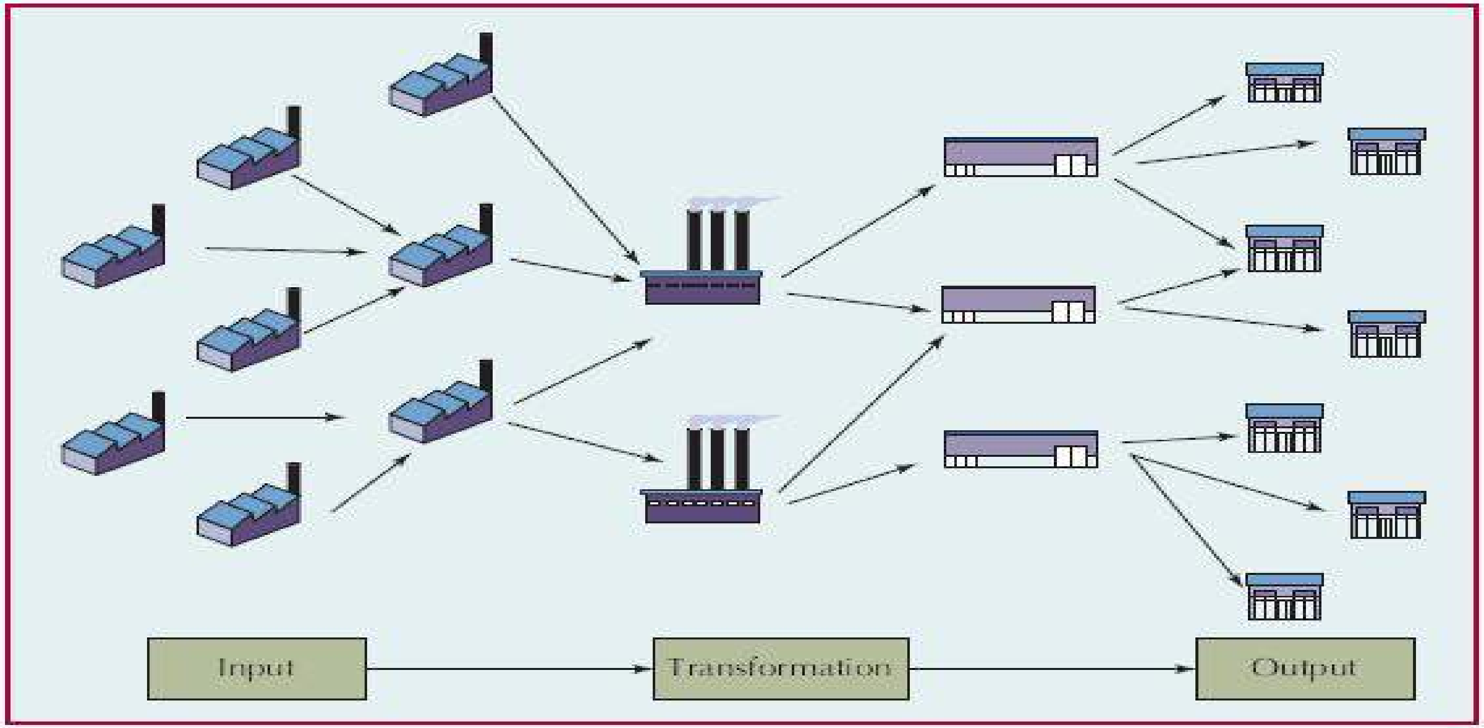
Supply Chain

Supply Chain – a sequence of activities and organizations involved in producing and delivering a good or service



Supply chain management

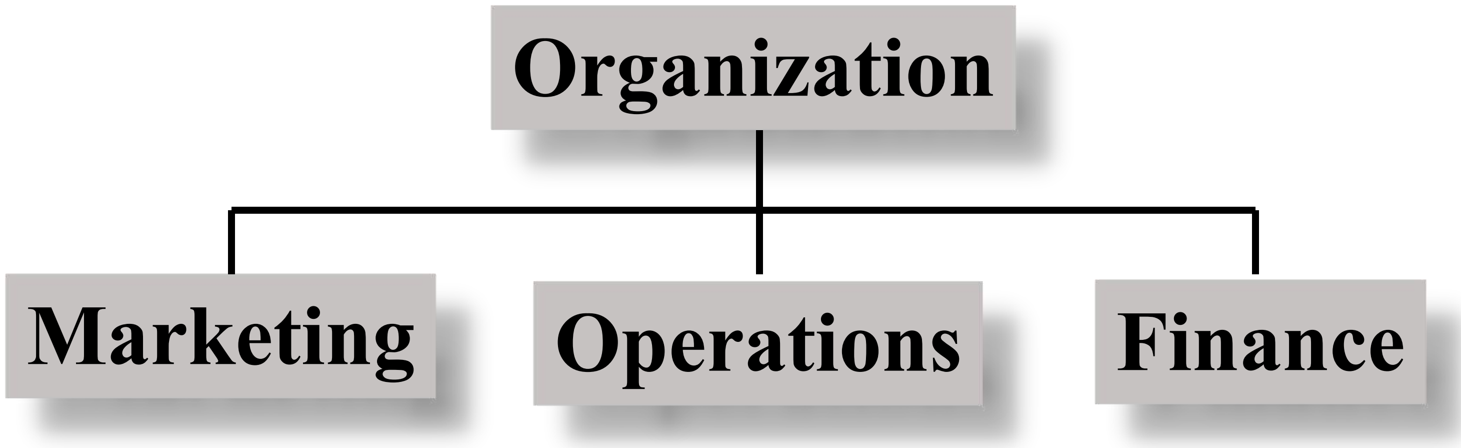
- management of the flow of information, products, and services across a network of customers, enterprises, and supply chain partners



Why Study Operations Management?

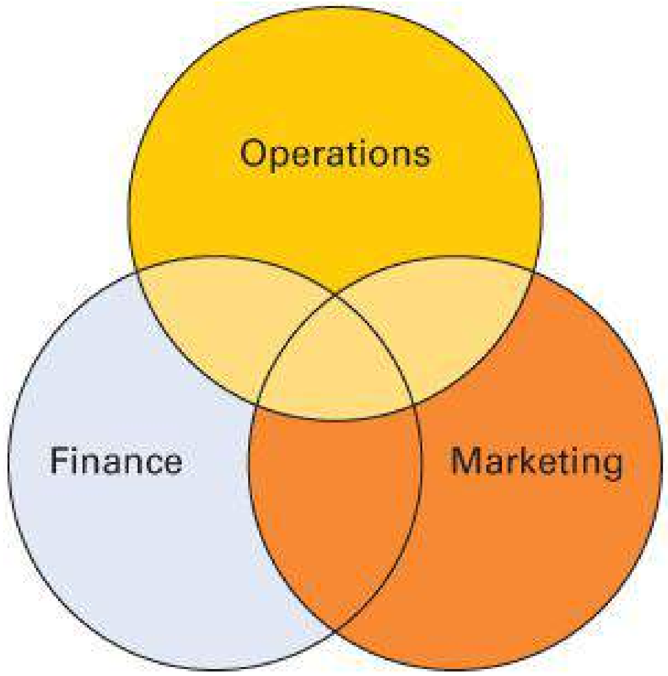
- Every aspect of business affects or is affected by operations
- Many service jobs are closely related to operations
    - Financial services
    - Marketing services
    - Accounting services
    - Information services
- Through learning about operations and supply chains you will have a better understanding of:
    - The world you live in
    - The global dependencies of companies and nations
    - Reasons that companies succeed or fail
    - The importance of working with others

Basic Functions of the Business Organization



Function Overlap

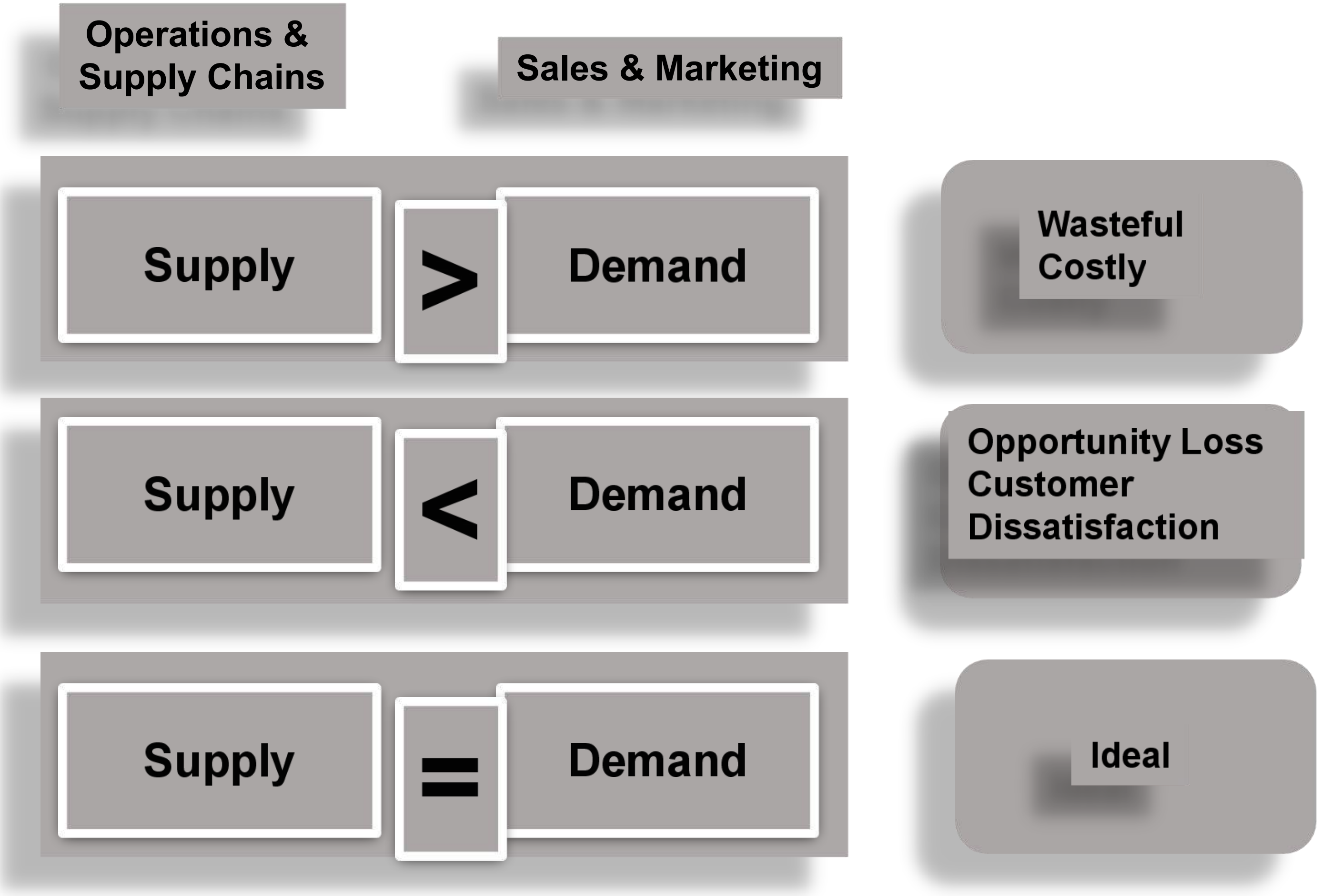
- Finance & Operations
  - Budgeting
  - Economic analysis of investment proposals
  - Provision of funds
- Marketing & Operations
  - Demand data
  - Product and service design
  - Competitor analysis
  - Lead time data



OM and Supply Chain Career Opportunities

- Operations manager
- Supply chain manager
- Production analyst
- Schedule coordinator
- Production manager
- Industrial engineer
- Purchasing manager
- Inventory manager
- Quality manager

Supply & Demand



Process/Operation

Process - one or more actions that transform inputs into outputs

Three Categories of Business Processes:	
Upper-management processes	These govern the operation of the entire organization.
Operational processes	These are core processes that make up the value stream.
Supporting processes	These support the core processes.

Process Variation

Four Sources of Variation:	
Variety of goods or services being offered	The greater the variety of goods and services offered, the greater the variation in production or service requirements.
Structural variation in demand	These are generally predictable. They are important for capacity planning.
Random variation	Natural variation that is present in all processes. Generally, it cannot be influenced by managers.
Assignable variation	Variation that has identifiable sources. This type of variation can be reduced, or eliminated, by analysis and corrective action.

Variations can be disruptive to operations and supply chain processes. They may result in additional costs, delays and shortages, poor quality, and inefficient work systems.

Scope of Operations Management

The scope of operations management ranges across the organization.

The operations function includes many interrelated activities such as:

- Forecasting
- Capacity planning
- Facilities and layout
- Scheduling
- Managing inventories
- Assuring quality
- Motivating employees
- Deciding where to locate facilities
- And more . . .

Historical Events in Operations Management

Era	Events/Concepts	Dates	Originator
Industrial Revolution	Steam engine	1769	James Watt
	Division of labor	1776	Adam Smith
	Interchangeable parts	1790	Eli Whitney
Scientific Management	Principles of scientific management	1911	Frederick W. Taylor
	Time and motion studies	1911	Frank and Lillian Gilbreth
	Activity scheduling chart	1912	Henry Gantt
	Moving assembly line	1913	Henry Ford

Historical Events in Operations Management

Era	Events/Concepts	Dates	Originator
Human Relations	Hawthorne studies	1930	Elton Mayo
	Motivation theories	1940s	Abraham Maslow
		1950s	Frederick Herzberg
		1960s	Douglas McGregor
Operations Research	Linear programming	1947	George Dantzig
	Digital computer	1951	Remington Rand
	Simulation, waiting line theory, decision theory, PERT/CPM	1950s	Operations research groups
	MRP, EDI, EFT, CIM	1960s, 1970s	Joseph Orlicky, IBM and others

Click to add text

Historical Events in Operations Management

Era	Events/Concepts	Dates	Originator
Quality Revolution	JIT (just-in-time)	1970s	Taiichi Ohno (Toyota)
	TQM (total quality management)	1980s	W. Edwards Deming, Joseph Juran
	Strategy and operations	1980s	Wickham Skinner, Robert Hayes
	Reengineering	1990s	Michael Hammer, James Champy
	Six Sigma	1990s	GE, Motorola

Historical Events in Operations Management

Era	Events/Concepts	Dates	Originator
Internet Revolution	Internet, WWW, ERP, supply chain management	1990s	ARPANET, Tim Berners-Lee SAP, i2 Technologies, ORACLE, Dell
	E-commerce	2000s	Amazon, Yahoo, eBay, Google, and others
Globalization	WTO, European Union, Global supply chains, Outsourcing, Service Science	1990s 2000s	China, India, Emerging economies

Historical Events in Operations Management

Era	Events/Concepts	Dates	Originator
Sustainability	Global warming Carbon footprint Green products Corporate social responsibility (CSR) UN Global Compact	Today	Numerous companies, statesmen, governments, United Nations, World Economic Forum

Key Issues for Operations and Supply Chain Managers Today

- Economic conditions
- Innovating
- Quality problems
- Risk management
- Competing in a global economy
- In the past, organizations did little to manage the supply chain beyond their own operations and immediate suppliers which led to numerous problems:
  - Oscillating inventory levels
  - Inventory stockouts
  - Late deliveries
  - Quality problems

Ethical Issues

- Financial statements
- Worker safety
- Product safety
- Quality
- The environment
- The community
- Hiring and firing workers
- Closing facilities
- Workers rights

Environmental Concerns

- Sustainability
  - Using resources in ways that do not harm ecological systems that support human existence
    - Sustainability measures often go beyond traditional environmental and economic measures to include measures that incorporate social criteria in decision making
    - All areas of business will be affected
      - Product and service design
      - Consumer education programs
      - Disaster preparation and response
      - Supply chain waste management
      - Outsourcing decisions

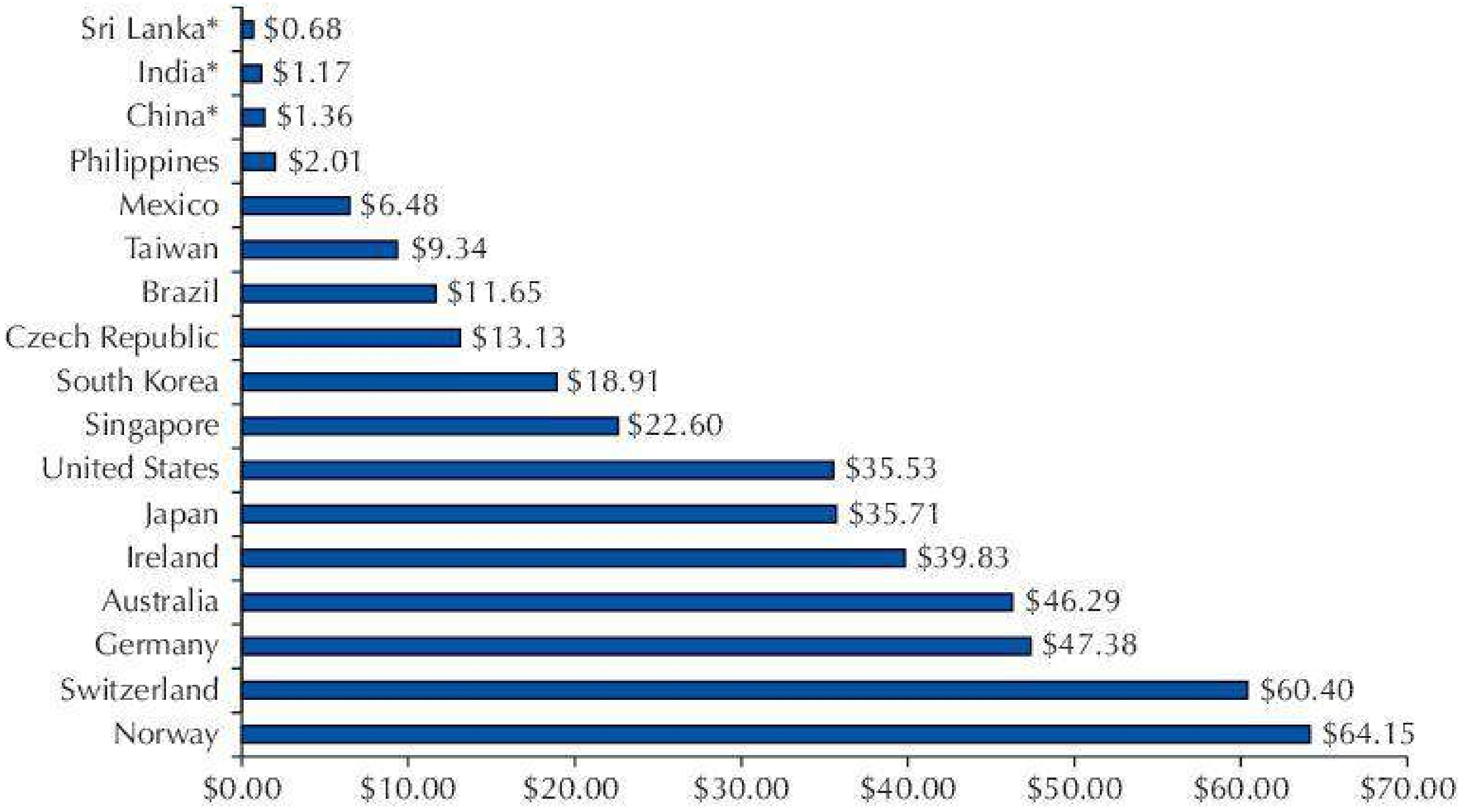
Digitization

- The exponential organization

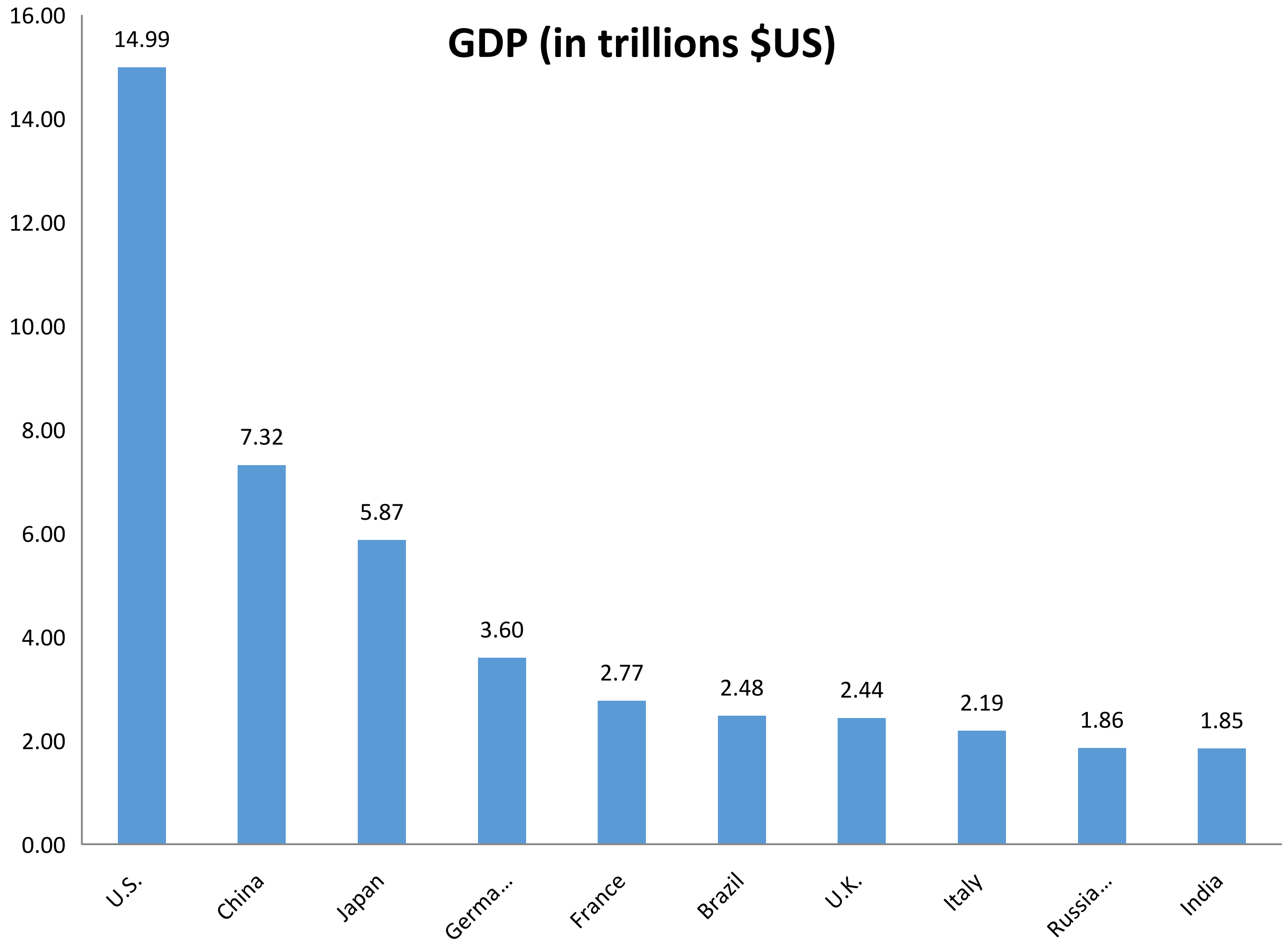
Globalization

- Why “go global”?
  - favorable cost
  - access to international markets
  - response to changes in demand
  - reliable sources of supply
  - latest trends and technologies
- Increased globalization
  - results from the Internet and falling trade barriers

Hourly Compensation

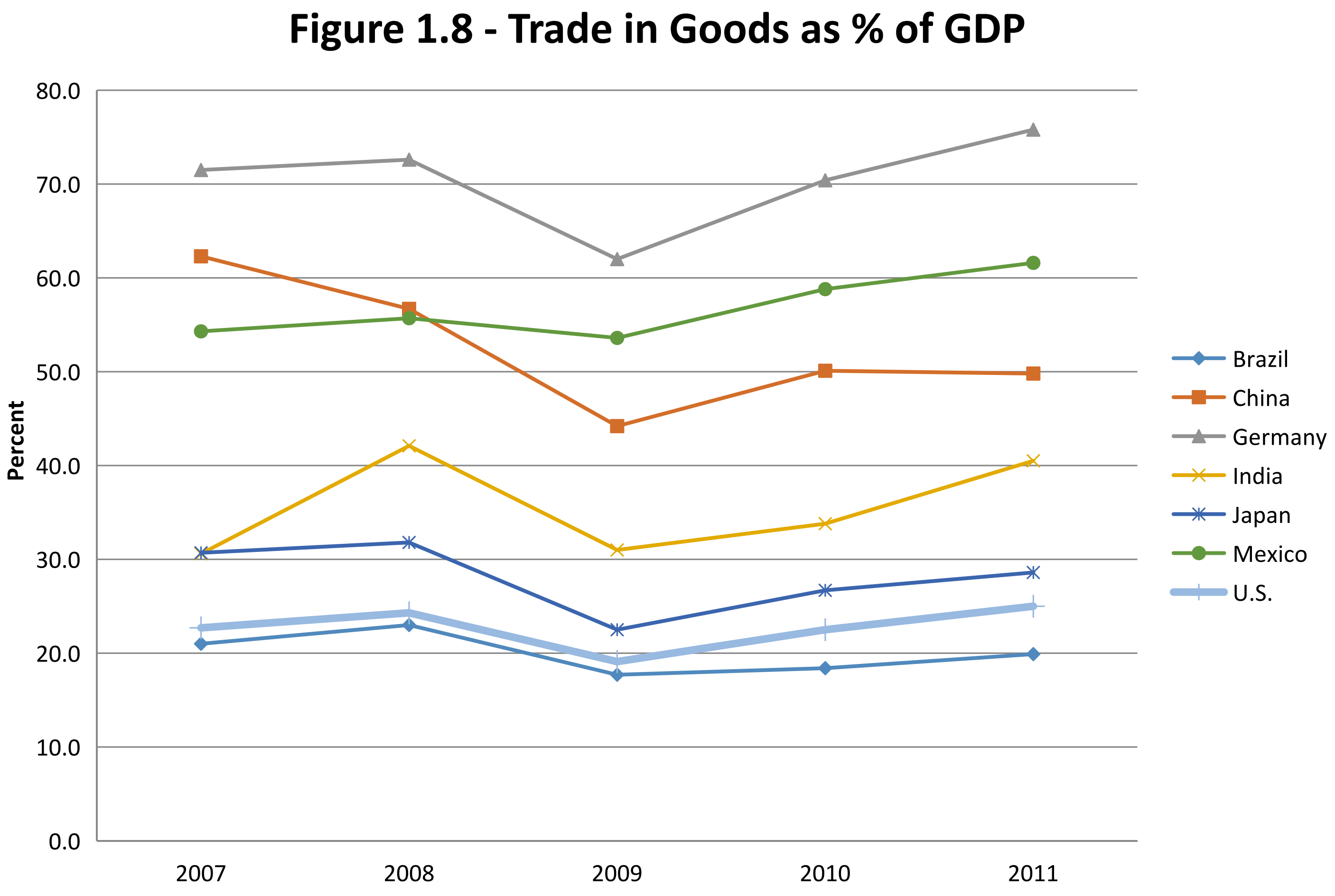


GDP

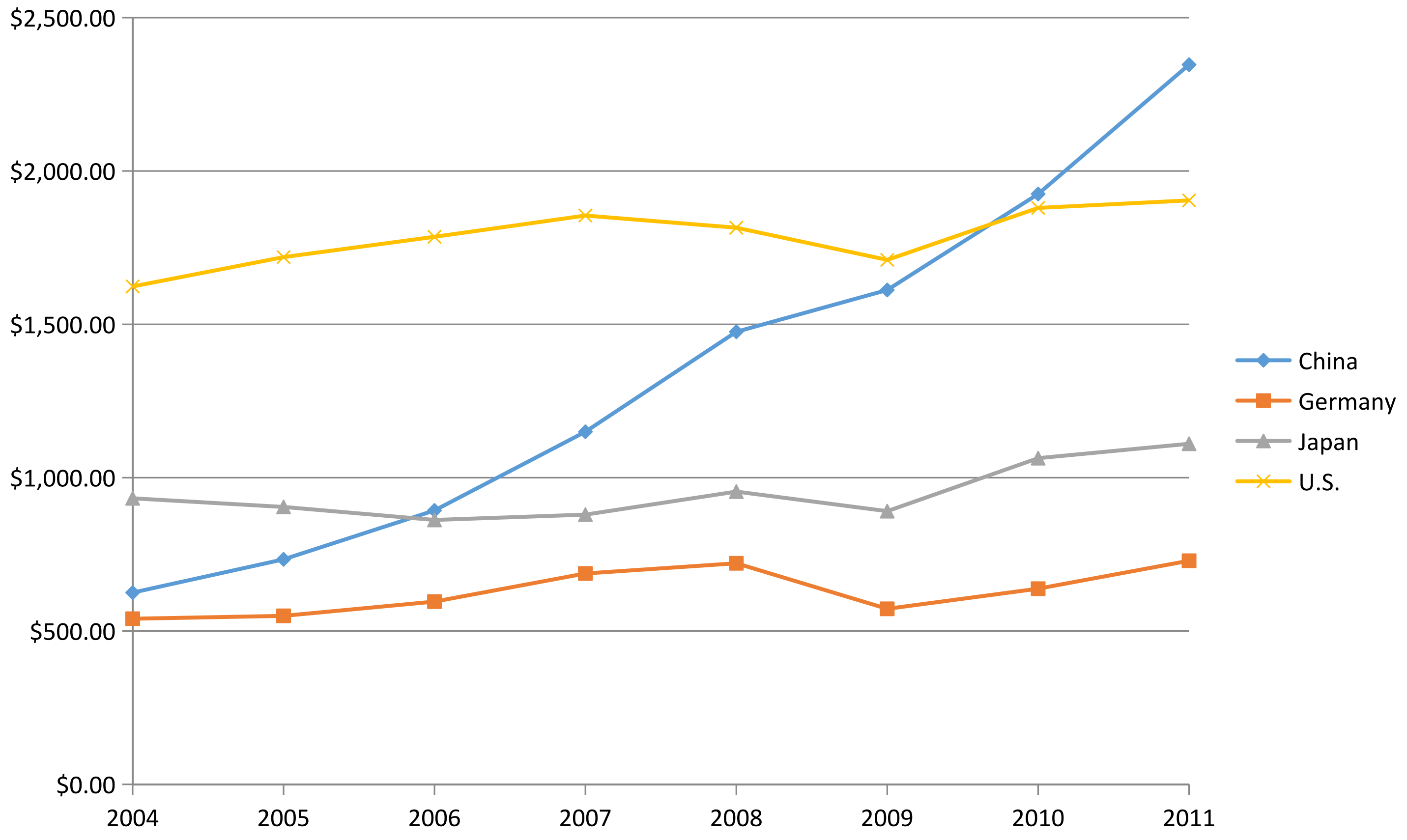


GDP (in trillions $US)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
14.99
7.32
5.87
3.60
2.77
2.48
2.44
2.19
1.86
1.85
U.S.
China
Japan
Germa...
France
Brazil
U.K.
Italy
Russia...
India

Trade in Goods, % of GDP



Manufacturing Output



Role of the Operations Manager

The Operations Function consists of all activities *directly* related to producing goods or providing services.

A primary function of the operations manager is to guide the system by decision making.

- System Design Decisions
- System Operation Decisions

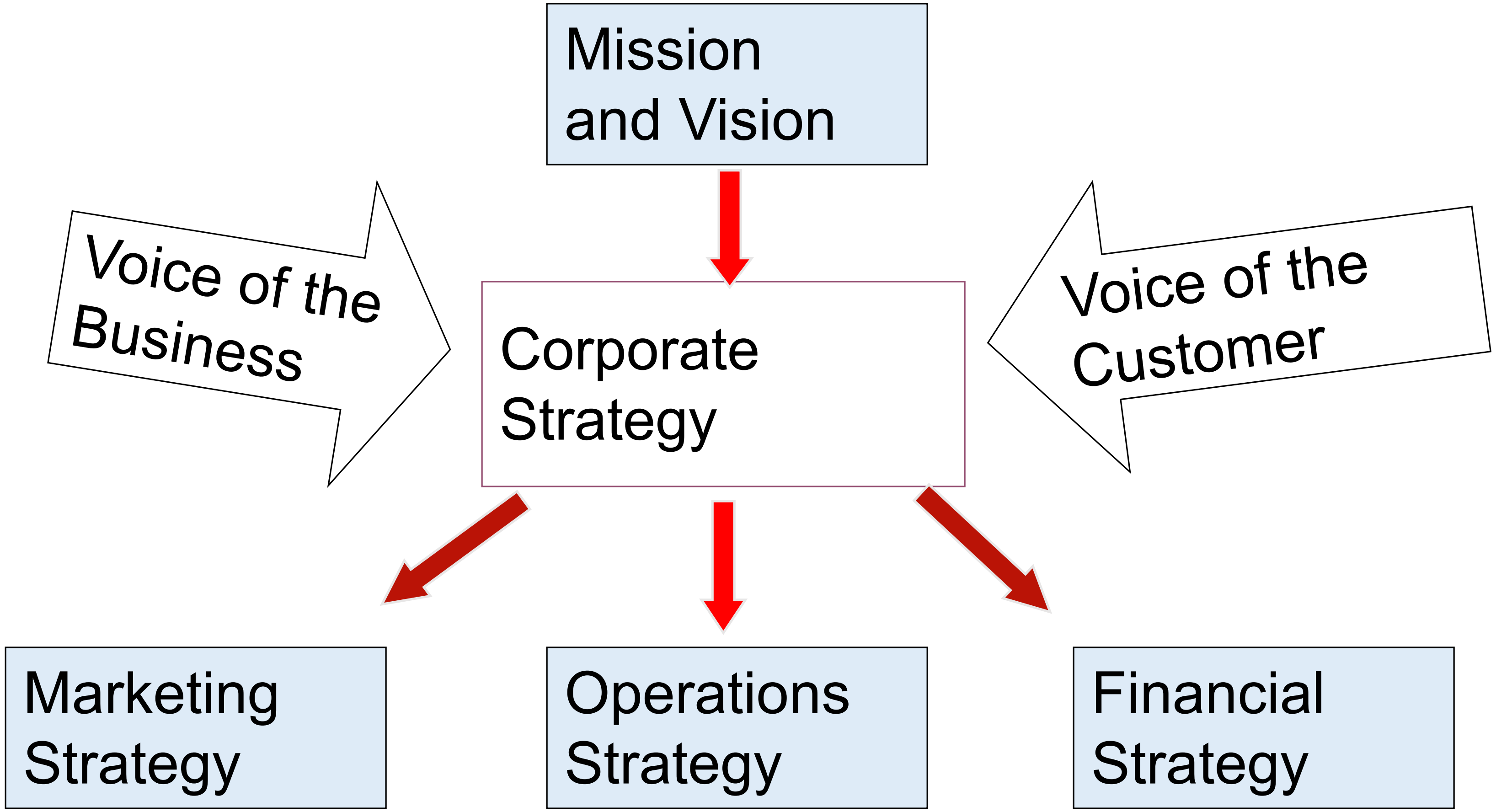
Design/Strategy and Operations

- How the mission of a company is accomplished
- Provides direction for achieving a mission
- Unites the organization
- Provides consistency in decisions
- Keeps organization moving in the right direction

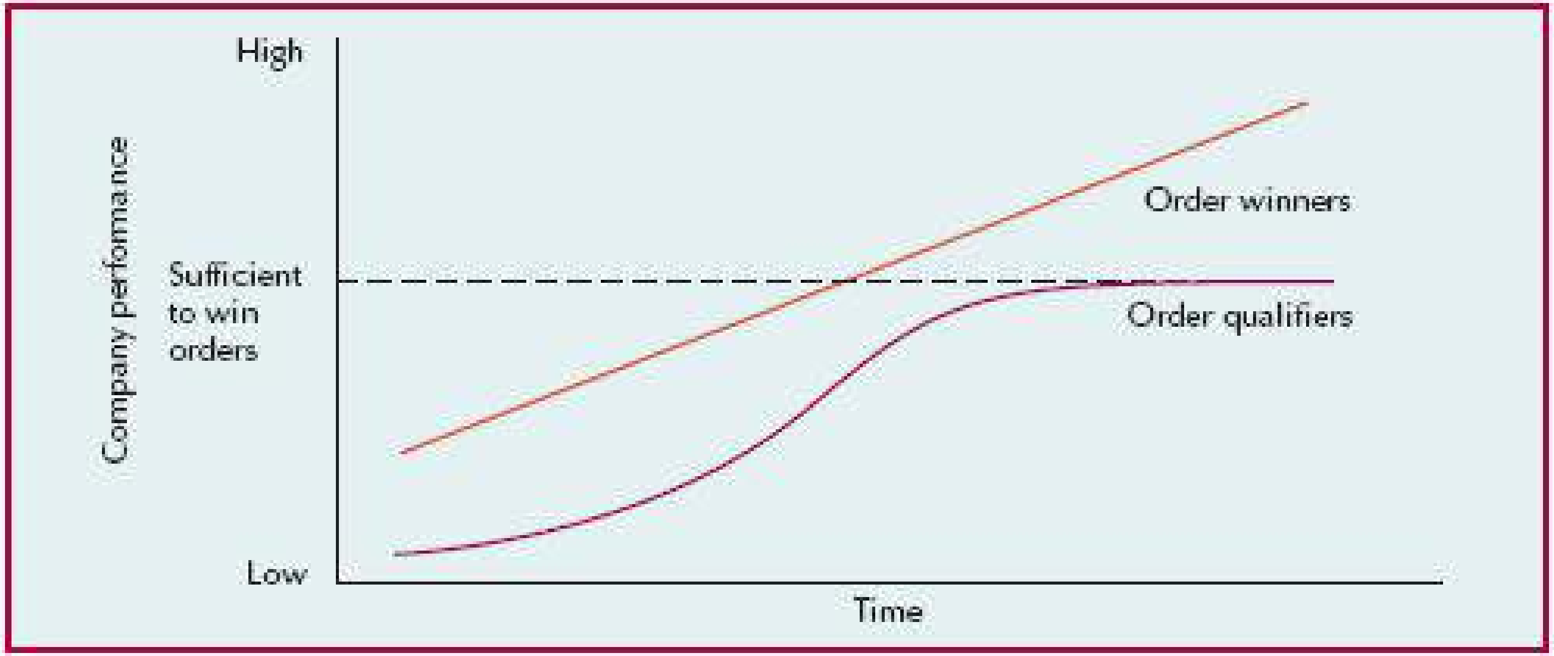
Strategy Formulation

1. Defining a primary task
   - What is the firm in the business of doing?
2. Assessing core competencies
   - What does the firm do better than anyone else?
3. Determining order winners and order qualifiers
   - What qualifies an item to be considered for purchase?
   - What wins the order?
4. Positioning the firm
   - How will the firm compete?
5. Deploying the strategy

Strategic Planning



Order Winners and Order Qualifiers



Source: Adapted from Nigel Slack, Stuart Chambers, Robert Johnston, and Alan Betts, *Operations and Process Management*, Prentice Hall, 2006, p. 47

Positioning the Firm

- Cost
- Speed
- Quality
- Flexibility

Positioning the Firm: Cost

- Waste elimination
  - relentlessly pursuing the removal of all waste
- Examination of cost structure
  - looking at the entire cost structure for reduction potential
- Lean production
  - providing low costs through disciplined operations

Positioning the Firm: Speed

- Fast moves, Fast adaptations, Tight linkages
- Internet
  - Customers expect immediate responses
- Service organizations
  - always competed on speed (McDonald’s, LensCrafters, and Federal Express)
- Manufacturers
  - time-based competition: build-to-order production and efficient supply chains
- Fashion industry
  - two-week design-to-rack lead time of Spanish retailer, Zara

Positioning the Firm: Quality

- Minimizing defect rates or conforming to design specifications
- Ritz-Carlton - one customer at a time
  - Service system designed to “move heaven and earth” to satisfy customer
  - Employees empowered to satisfy a guest’s wish
  - Teams set objectives and devise quality action plans
  - Each hotel has a quality leader

Positioning the Firm: Flexibility

- Ability to adjust to changes in product mix, production volume, or design
- Mass customization
  - mass production of customized parts
- National Bicycle Industrial Company
  - offers 11,231,862 variations
  - delivers within two weeks at costs only 10% above standard models

Competing on Innovation

Questions

- Why is it difficult to match supply and demand?
- How do firms position themselves?
- What **goes into making a strategic plan for an organization?**
- What is the difference between order qualifiers, order winners and core competencies?

- **Class presentations:**

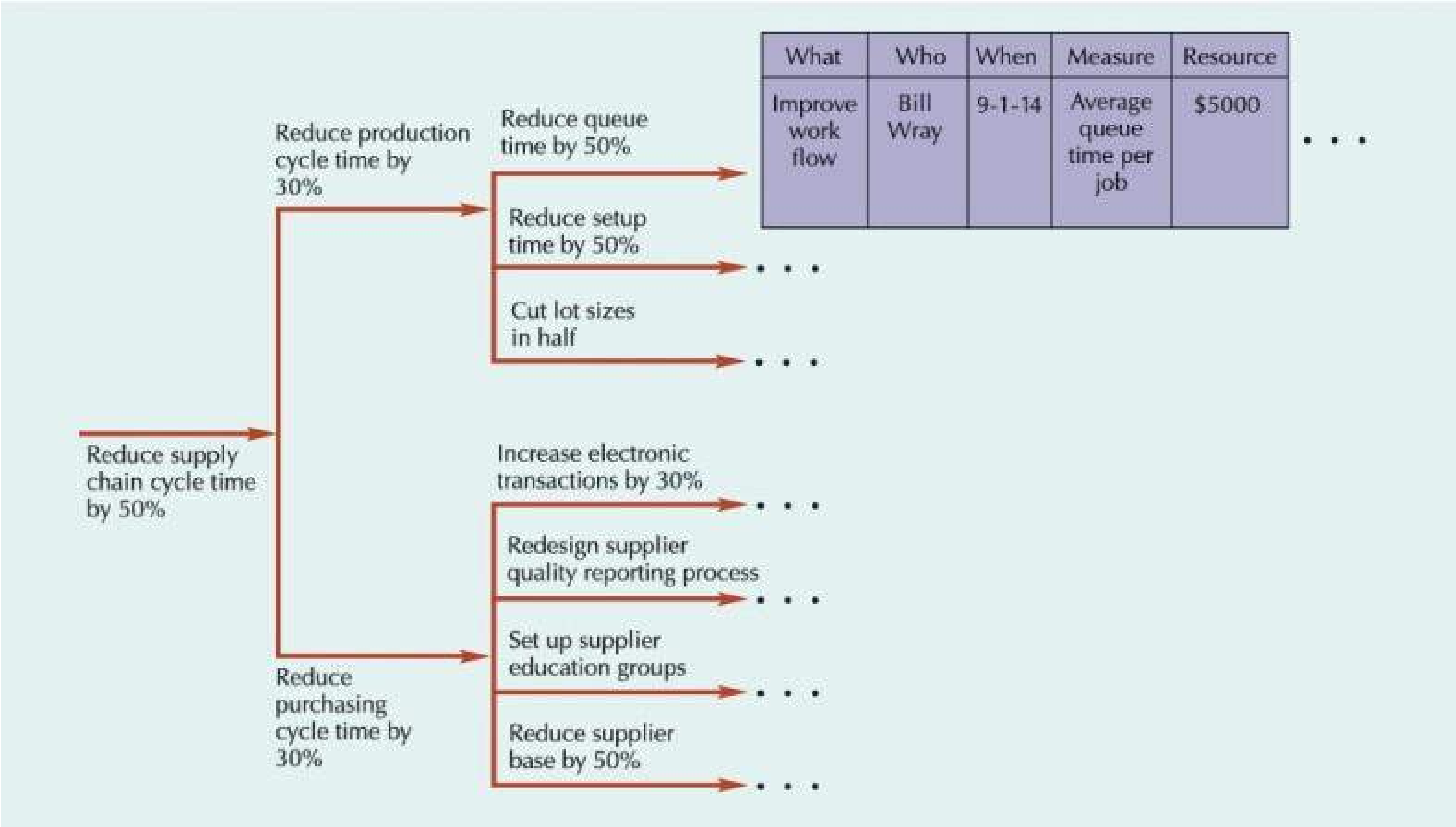
1. Choose three companies that you are interested in learning about this semester. Go to the company websites and find out about their where their products are made and how their supply chain is coordinated. You should see a separate section for suppliers. Explore.

2. From your travels (domestically or internationally), what differences have you encountered in the goods or services provided? Think about how companies doing business in different countries need to adjust their operations.

Policy Deployment

- Policy deployment
  - translates corporate strategy into measurable objectives
- Hoshins
  - action plans generated from the policy deployment process

Policy Deployment

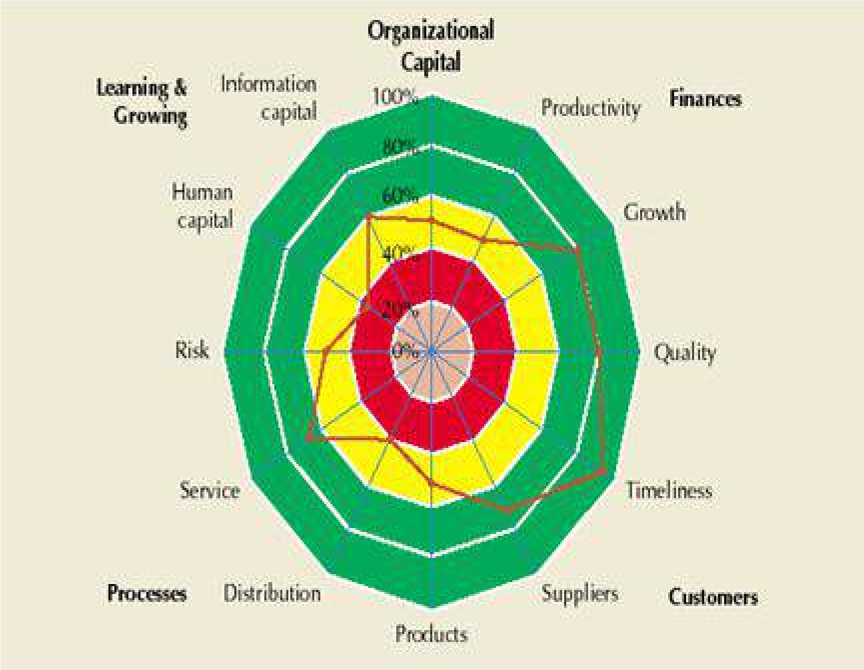


Derivation of an Action Plan Using Policy Deployment

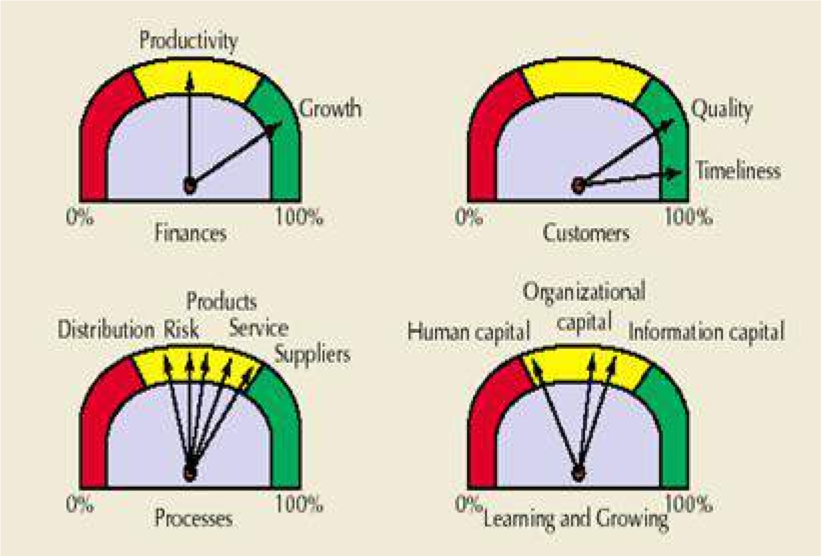
Assessing an organization

- Balanced scorecard
  - measuring more than financial performance
    - finances
    - customers
    - processes
    - learning and growing
- Key performance indicators
  - set of measures to help managers evaluate performance in critical areas

Balanced Scorecard

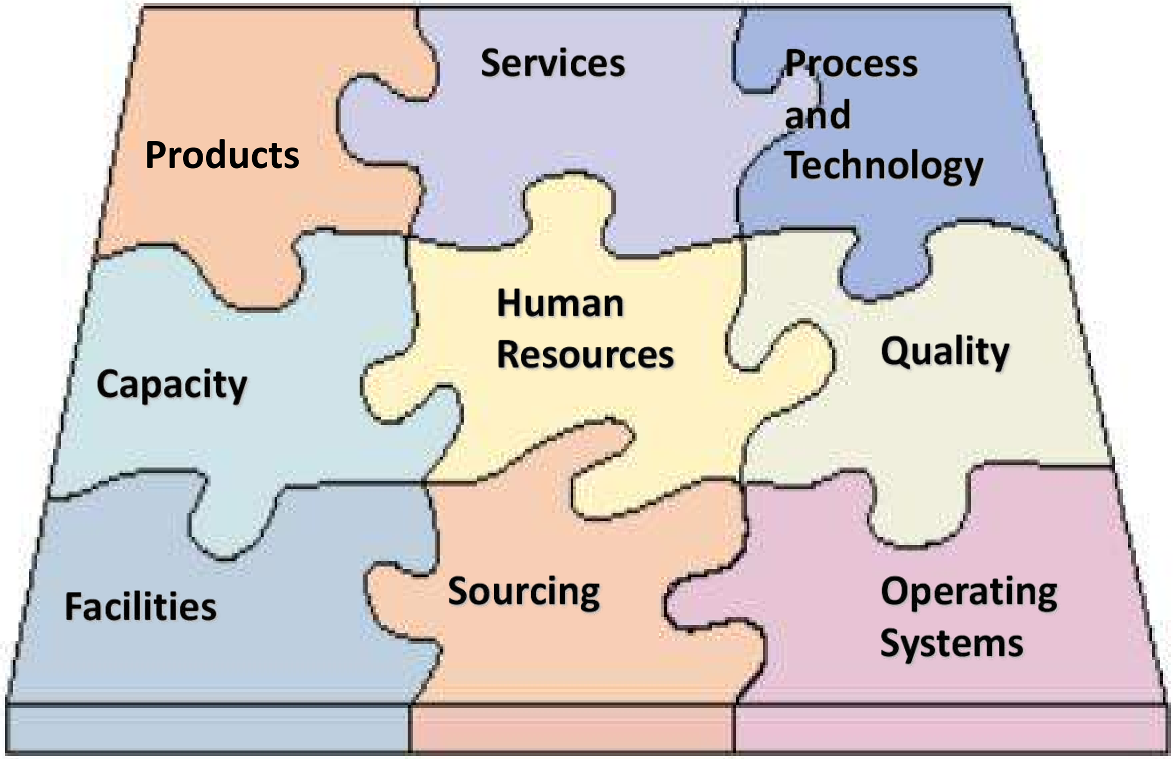


Radar Chart



Dashboard

Design/Strategy



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- System Operation Decisions

System Design Decisions

- **System Design**
  - – Capacity
  - – Facility location
  - – Facility layout
  - – Product and service planning
  - – Acquisition and placement of equipment
- These are typically strategic decisions that
  - usually require long-term commitment of resources
  - determine parameters of system operation

System Operation Decisions

- **System Operation**
  - These are generally tactical and operational decisions
    - Management of personnel
    - Inventory management and control
    - Scheduling
    - Project management
    - Quality assurance
- Operations managers spend more time on system operation decision than any other decision area
  - **They still have a vital stake in system design**

OM Decision Making

- Most operations decisions involve many alternatives that can have quite different impacts on costs or profits
- Typical operations decisions include:
  - ***What:*** What resources are needed, and in what amounts?
  - ***When:*** When will each resource be needed? When should the work be scheduled? When should materials and other supplies be ordered?
  - ***Where:*** Where will the work be done?
  - ***How:*** How will he product or service be designed? How will the work be done? How will resources be allocated?
  - ***Who:*** Who will do the work?

General Approach to Decision Making

- Modeling is a key tool used by all decision makers
  - ***Model*** - an abstraction of reality; a simplification of something.
  - Common features of models:
    - They are simplifications of real-life phenomena
    - They omit unimportant details of the real-life systems they mimic so that attention can be focused on the most important aspects of the real-life system

Understanding Models

- Keys to successfully using a model in decision making
  - What is its purpose?
  - How is it used to generate results?
  - How are the results interpreted and used?
  - What are the model’s assumptions and limitations?

Benefits of Models

1. Models are generally easier to use and less expensive than dealing with the real system
2. Require users to organize and sometimes quantify information
3. Increase understanding of the problem
4. Enable managers to analyze “What if?” questions
5. Serve as a consistent tool for evaluation and provide a standardized format for analyzing a problem
6. Enable users to bring the power of mathematics to bear on a problem

Model Limitations

- Quantitative information may be emphasized at the expense of qualitative information
- Models may be incorrectly applied and the results misinterpreted
  - This is a real risk with the widespread availability of sophisticated, computerized models are placed in the hands of uninformed users.
- The use of models does not guarantee good decisions.

Quantitative Approaches

- A decision making approach that frequently seeks to obtain a mathematically optimal solution
  - Linear programming
  - Queuing techniques
  - Inventory models
  - Project models
  - Forecasting techniques
  - Statistical models

Metrics and Trade-Offs

- Performance Metrics
  - All managers use metrics to manage and control operations
    - Profits
    - Costs
    - Quality
    - Productivity
    - Flexibility
    - Inventories
    - Schedules
    - Forecast accuracy
- Analysis of Trade-Offs
  - A trade-off is giving up one thing in return for something else
    - Carrying more inventory (an expense) in order to achieve a greater level of customer service

Systems Approach

- *System* - a set of interrelated parts that must work together
  - The business organization is a system composed of subsystems
    - marketing subsystem
    - operations subsystem
    - finance subsystem
- The systems approach
  - Emphasizes *interrelationships among subsystems*
  - Main theme is that *the whole is greater than the sum of its parts*
  - The output and objectives of the organization take precedence over those of any one subsystem

Establishing Priorities

- In nearly all cases, certain issues or items are more important than others
- Recognizing this allows managers to focus their attention to those efforts that will do the most good
  - Pareto Phenomenon - a few factors account for a high percentage of occurrence of some event(s)
    - The critical few factors should receive the highest priority
    - This is a concept that is appropriately applied to all areas and levels of management

Learning Objectives of this Course

- Gain an appreciation of strategic importance of operations and supply chain management in a global business environment
- Understand how operations relates to other business functions
- Develop a working knowledge of concepts and methods related to designing and managing operations and creating value along the supply chains
- Develop a skill set for continuous improvement

Quality Management

Quality improvement in modern business environment

Prof. Tarun Sharma

Contents/ Learning activities

- **Revisit: Quality dimensions, definitions, terminology**
- Statistical methods for quality control and Improvement
  - SPC
  - DOX
  - AS
- Management aspects of quality improvement
  - Six sigma

Definitions – Meaning of Quality and Quality Improvement

1.1.1 The Eight Dimensions of Quality

1. Performance
2. Reliability
3. Durability
4. Serviceability
5. Aesthetics
6. Features
7. Perceived Quality
8. Conformance to Standards

Definition

Quality means fitness for use.

- This is a traditional definition
- Quality of design
- Quality of conformance

Definition

Quality is inversely proportional to variability.

This is a modern definition of quality

The Transmission Example

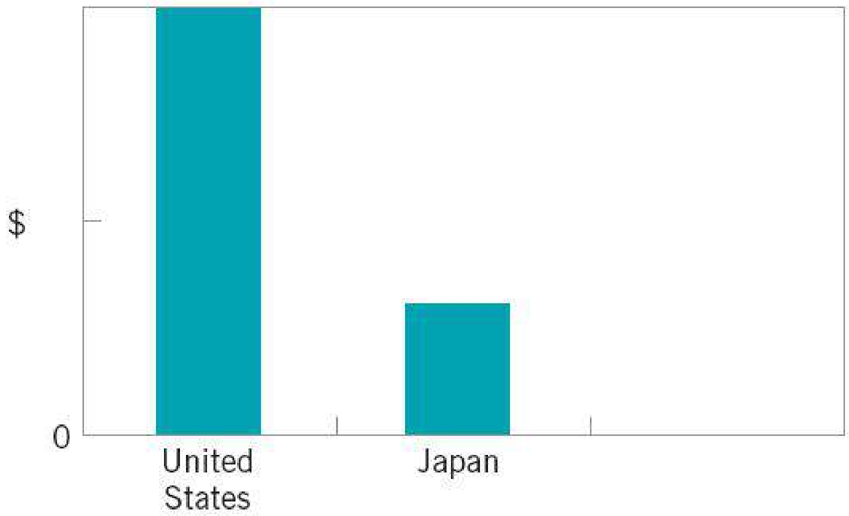


FIGURE 1.1 Warranty costs for transmissions.

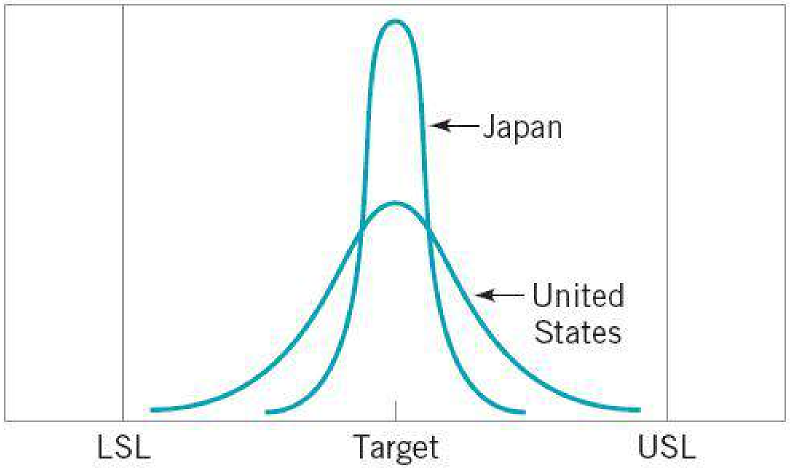


FIGURE 1.2 Distributions of critical dimensions for transmissions.

- Quality is inversely proportional to variability
- Customer doesn't see the mean of the process, s/he only sees the variability around the target that you have not removed - Jack Welch (retired CEO - GE)

What is Quality Improvement?

- Quality Improvement is the reduction of variability in processes and products.

- Excessive variability in process performance often results in waste.

- Quality Improvement is the reduction of waste.

Quality Terminology

- Quality / Critical-To-Quality Characteristics (CTQ)
  - Every product possesses a number of elements that jointly describe what the user or consumer thinks of as quality
    - Physical: length, weight, voltage, viscosity
    - Sensory: taste, appearance, color
    - Time Orientation: reliability, durability, serviceability

- Quality Engineering
  - Set of operational, managerial, and technical activities that a company uses to ensure that the quality characteristics of a product are at the nominal or required levels and that the variability around these desired levels is minimum.

Quality Terminology

- Data Types
  - Variables data are usually continuous measurements, such as length, voltage, or viscosity.
  - Attributes data, on the other hand, are usually discrete data, often taking the form of counts.
- Specifications
  - For a manufactured product, the specifications are the desired measurements for the quality characteristics of the components and subassemblies that make up the product, as well as the desired values for the quality characteristics in the final product.
  - In the service industries, specifications are typically in terms of the maximum amount of time to process an order or to provide a particular service. (Cycle Time)

Quality Terminology

- Nominal / Target Value
  - A value of a measurement that corresponds to the desired value for that quality characteristic
- Upper Specification Limit (USL)
  - The largest allowable value for a quality characteristic
- Lower Specification Limit (LSL)
  - The smallest allowable value for a quality characteristic
- Nonconforming Product
  - Products that fail to meet one or more of its specifications.
- Nonconformity
  - Specific type of failure

Quality Terminology

- Defective, Defects
  - A nonconforming product is considered defective if it has one or more defects, which are nonconformities that are serious enough to significantly affect the safe or effective use of the product.

- Concurrent Engineering
  - Stressed a team approach to design, with specialists in manufacturing, quality engineering, and other disciplines working together with the product designer at the earliest stages of the product design process.

Statistical methods for quality control and improvement

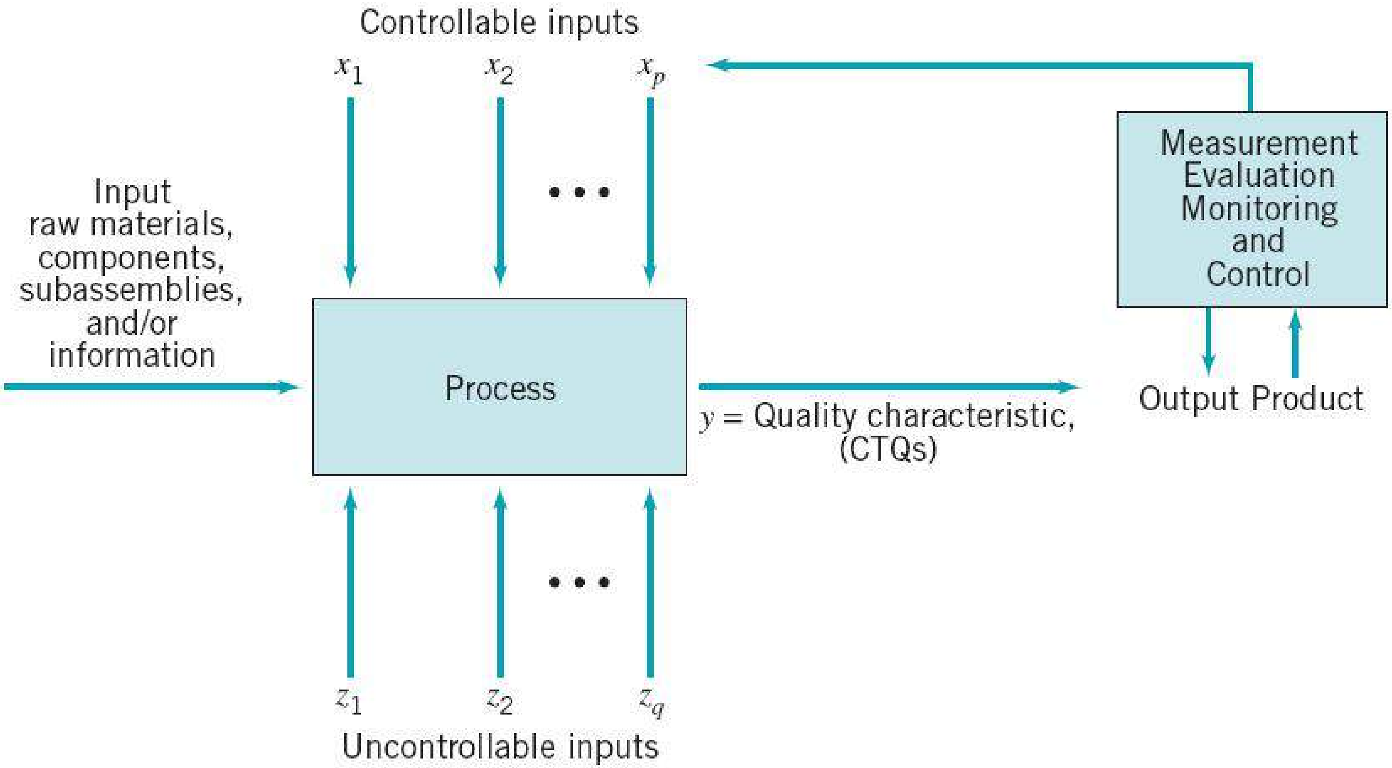


FIGURE 1.3 Production process inputs and outputs.

Statistical methods

- Statistical process control (SPC)
  - Control charts, plus other problem-solving tools
  - Useful in monitoring processes, reducing variability through elimination of assignable causes
  - On-line technique
- Designed experiments (DOX)
  - Discovering the key factors that influence process performance
  - Process optimization
  - Off-line technique
- Acceptance Sampling

Statistical Process Control (SPC)

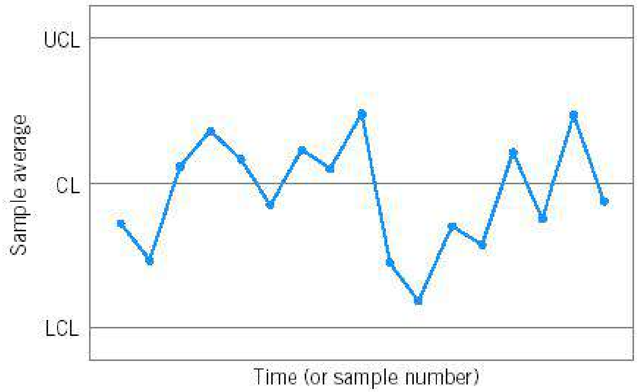
- Walter A. Shewart (1891-1967)
- Trained in engineering and physics
- Long career at Bell Labs
- 

Figure 1-4 A typical control chart.

- A control chart is one of the primary techniques of statistical process control (SPC)
- Classically, control charts are applied to the output variable(s) in a system
- However, in some cases they can be usefully applied to the inputs as well.

Design of Experiments

- Approach to systematically vary the controllable input factors in the process and determining the effect these factors have on the output product parameters.
- Off-line improvement technique
- Leads to a model of the process
- One major type of designed experiment is the factorial design, in which factors are varied together in such a way that all possible combinations of factor levels are tested.

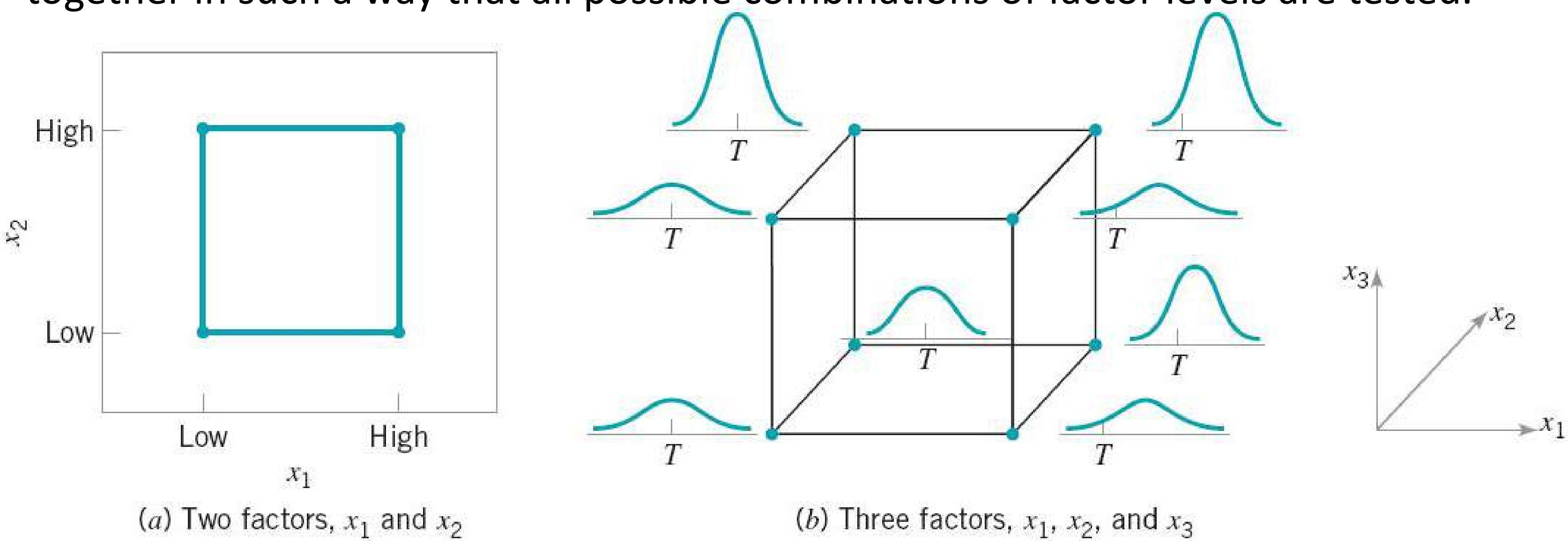


FIGURE 1.5 Factorial designs for the process in Fig. 1.3.

Acceptance Sampling

- Inspection and classification of a sample of units selected at random from a larger batch or lot and the ultimate decision about disposition of the lot, usually occurs at two points: incoming raw materials or components and final production.

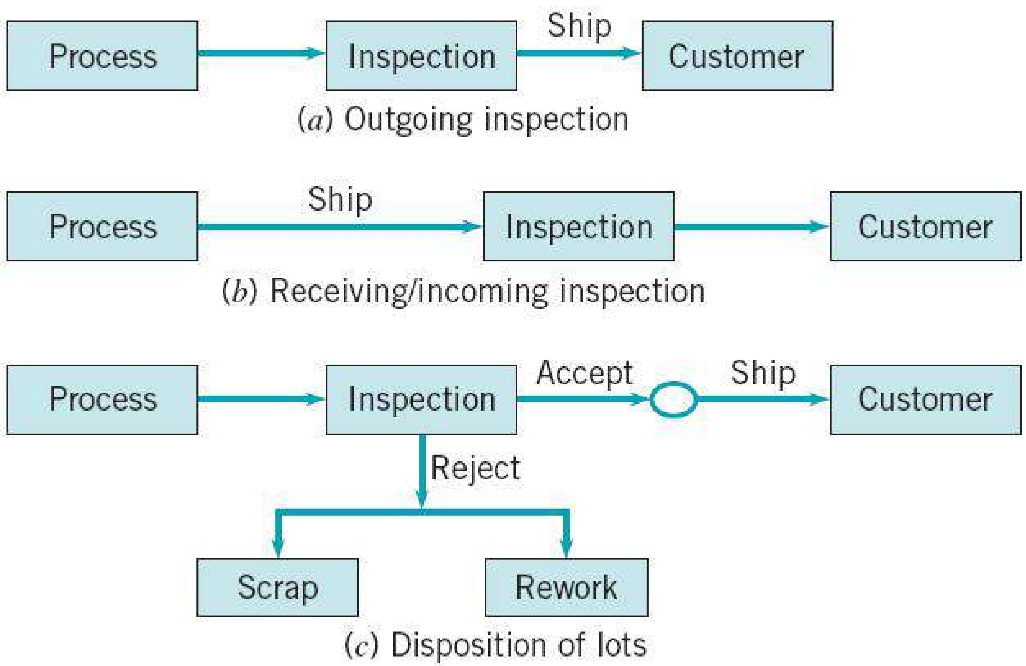


FIGURE 1.6 Variations of acceptance sampling.

Modern Quality Assurance Systems

- Modern quality assurance systems usually place less emphasis on acceptance-sampling and attempt to make statistical process control and designed experiments the focus of their efforts.

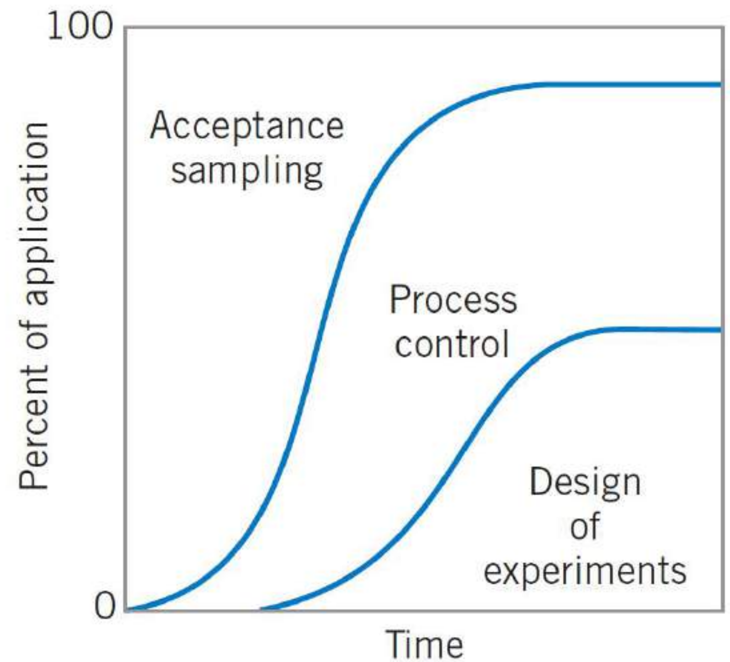


Figure 1.7 Phase Diagram of the Use of Quality-Engineering Methods

Quality Engineering

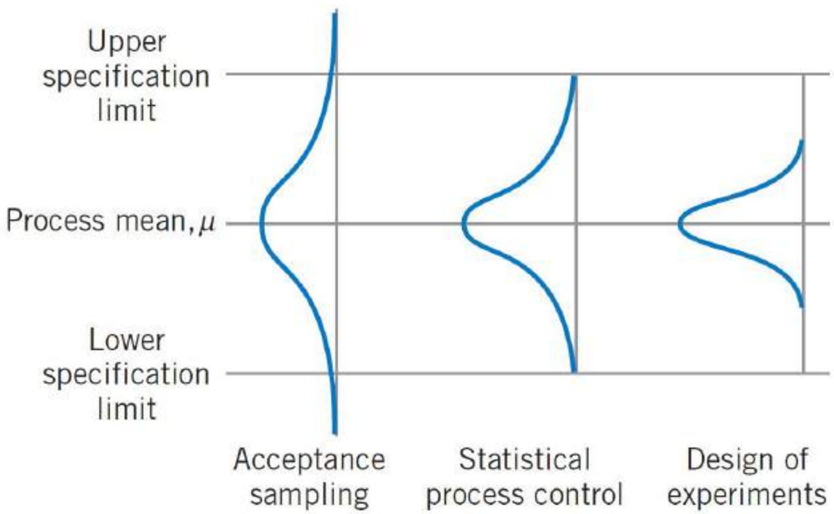


Figure 1.8 Application of Quality-Engineering Techniques and the Systematic Reduction of Process Variability

- The primary objective of quality engineering efforts is the systematic reduction of variability in the key quality characteristics of the product.

Management aspects of Quality Improvement

- The management system of an organization must be organized to properly direct the overall quality improvement philosophy and ensure its deployment in all aspects of the business.

- Effective management of quality requires the execution of three activities:
  1. Quality Planning
  2. Quality Assurance
  3. Quality Control and Improvement

Quality Planning

- Quality planning is a strategic activity
- Quality planning involves
  - identifying customers, both external and those that operate internal to the business, and identifying their needs (this is sometimes called listening to the voice of the customer [VOC]).
  - Design and develop products or services that meet or exceed customer expectations.
  - Determine how these products and services will be realized.
  - Planning for quality improvement on a specific, systematic basis is also a vital part of this process.

Quality Assurance

- Quality assurance is the set of activities that ensures that quality levels of products and services are properly maintained and that supplier and customer quality issues are properly resolved.

- Quality system documentation involves four components.
  - Policy generally deals with what is to be done and why.
  - Procedures focus on the methods and personnel that will implement policy.
  - Work instructions and specifications are usually product-, department-, tool-, or machine-oriented.
  - Records are a way of documenting the policies, procedures, and work instructions that have been followed.

- Development, maintenance, and control of documentation are important quality assurance functions.

“Say what you are going to do, and do what you say.”

Quality Control

- Quality control and improvement involve the set of activities used to ensure that the products and services meet requirements and are improved on a continuous basis.

- Variability is often a major source of poor quality and statistical techniques, including SPC and designed experiments, are the major tools of quality control and improvement.

- Quality improvement is often done on a project-by-project basis and involves teams led by personnel with specialized knowledge of statistical methods and experience in applying them.

- Projects should be selected so that they have significant business impact and are linked with the overall business goals for quality identified during the planning process.

Six Sigma

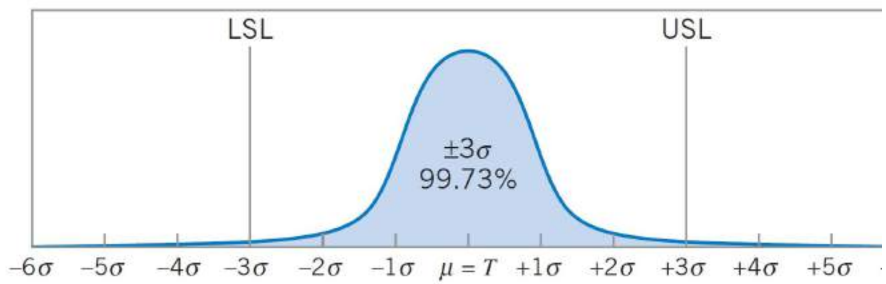
- **Six-Sigma is a business strategy** that seeks to improve business performance by identifying and removing the causes of defects and errors
- Motorola developed the **Six-Sigma program** in the late 1980s as a response to the demand for their products.
- The focus of six-sigma is reducing variability in key product quality characteristics to the level at which failure or defects are extremely unlikely.

Six Sigma

- Probability of producing a product within these specifications is 0.9973, which corresponds to 2700 parts per million (ppm) defective.
- This is referred to as **three-sigma quality performance which sounds pretty good**
- Now suppose we have a product that consists of an assembly of 100 independent components and all 100 parts must be non defective for the product to function satisfactorily.
- The probability that any specific unit of product is non defective is

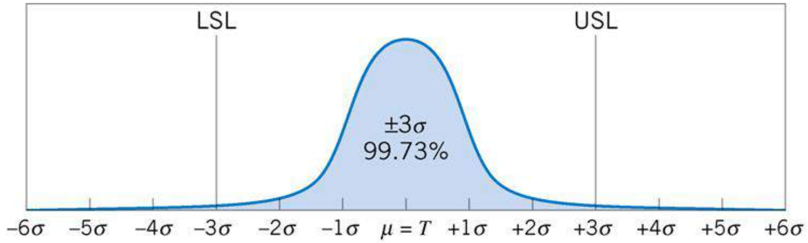
0.9973 * 0.9973 *. . .* 0.9973 = 0.7631

- 23.7% of products are defective.



Spec. Limit	Percent Inside Specs	ppm Defective
±1 Sigma	68.27	317300
±2 Sigma	95.45	45500
±3 Sigma	99.73	2700
±4 Sigma	99.9937	63
±5 Sigma	99.999943	0.57
±6 Sigma	99.9999998	0.002

(a) Normal distribution centered at the target (T)



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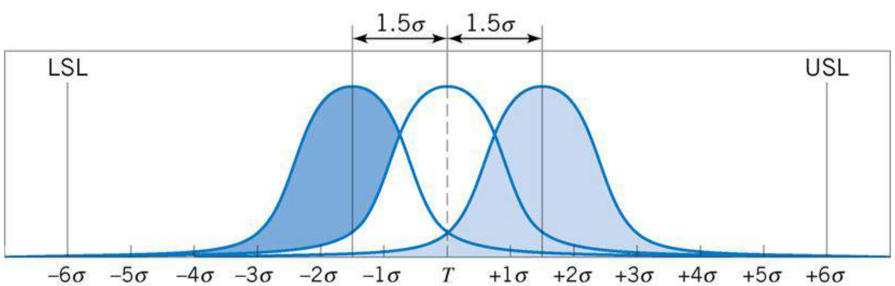
(a) Normal distribution centered at the target (*T*)



Spec. Limit	Percent inside specs	ppm Defective
±1 Sigma	30.23	697700
±2 Sigma	69.13	608700
±3 Sigma	93.32	66810
±4 Sigma	99.3790	6210
±5 Sigma	99.97670	233
±6 Sigma	99.999660	3.4

(b) Normal distribution with the mean shifted by ±1.5σ from the target

- The Motorola six-sigma concept is to reduce the variability in the process so that the specification limits are at least six standard deviations from the mean.
- Generally, we can only make predictions about process performance when the process is **stable.**
- If the mean is drifting around, and ends up as much as 1.5 standard deviations off target, a prediction of 3.4 ppm defective may not be very reliable, because the mean might shift by *more than the "allowed" 1.5 standard deviations.*

- Suppose a measurement is distributed normally and has a mean value of 0.5 m. with a standard deviation of 0.002 m.

1) How many standard deviations away is a measurement value of 0.5039 and 0.4961 from the mean?

2) Given the distribution how likely (what is the probability) that an operator will get a measurement
   a) Higher than 0.5039
   b) Lower than 0.4961
   c) Between 0.5039 & 0.4961

Key points

- Distinction between Specification/tolerance limits and the Control limits

- A quality attribute whose 6 sigma variation (on each side of the mean) coincides with the specification limits is of better quality than the same quality attribute having its 3 sigma variation (on each side of the mean) coincide with the same specification limit.

- Are the control limits of the control chart same as the 3 sigma variation in the quality attribute as measured in the entire population of that product?

- The control limits on the control chart are the in terms of the standard deviation of the statistic plotted on the chart. It is not the standard deviation of the quality characteristic.

Central Limit Theorem

- One of the most important results in statistics. Allows us to apply many statistical techniques to data that are not normally distributed!

$$E(\bar{x}) = \mu \qquad\qquad \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

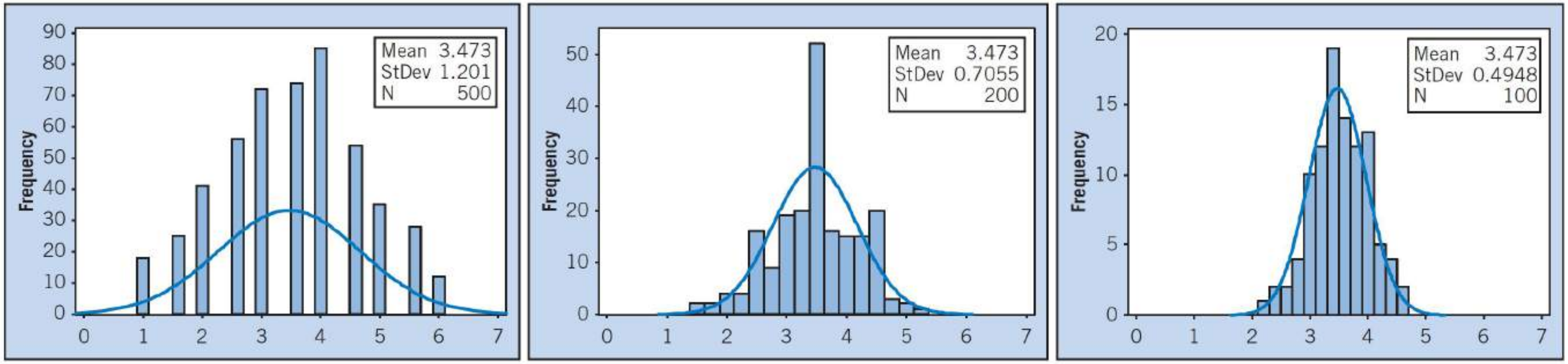


Figure 4.20 Distribution Created by Averaging 2, 5, and 10 Values Together

- Suppose a measurement is distributed normally and has a mean value of 0.5 m. with a standard deviation of 0.002 m.

1) How many standard deviations away is a measurement value of 0.5039 and 0.4961 from the mean?

2) Given the distribution how likely (probability) that an operator will get a measurement higher than 0.5039 and lower than 0.4961?

3) If instead of single observations, sample sizes of 5 are taken and the mean value of the sample is used (as is in a control chart) what will be the 95% confidence interval for the sample mean?

Six Sigma Quality

- Process performance is not predictable unless the process behavior is stable.
- However, no process or system is ever truly stable, and even in the best of situations, disturbances occur.
- These disturbances can result in the process mean shifting off-target, an increase in the process standard deviation, or both.
- The concept of a six-sigma process is one way to **model this behavior.**

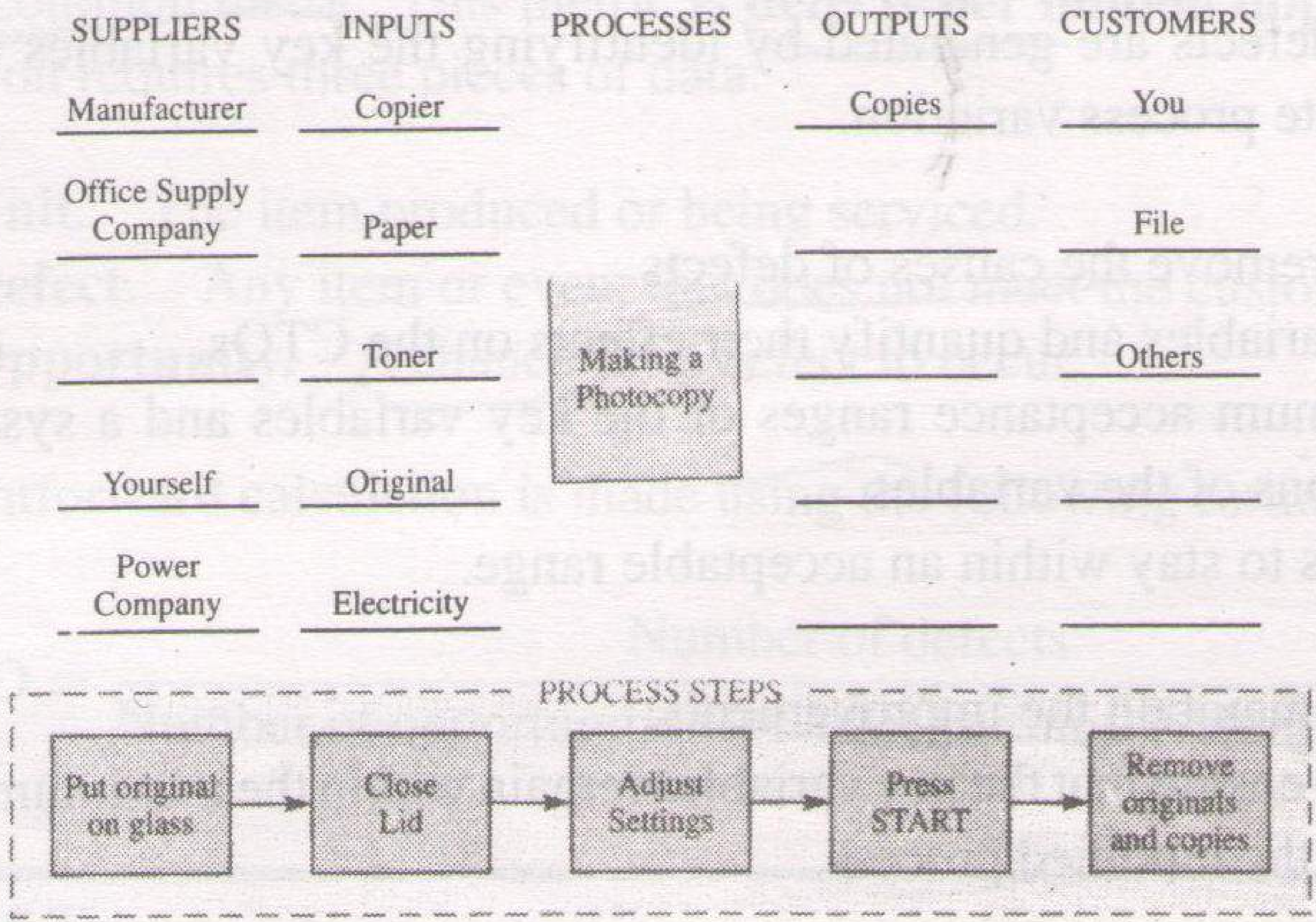
Six Sigma

- Typical six-sigma projects are four to six months in duration and are selected for their potential impact in the business.
- Six-sigma uses a specific five-step problem solving approach: Define, Measure, Analyze, Improve, and Control (DMAIC).

What's Your "Belt"?

Companies involved in a six-sigma effort utilize specially trained individuals, called Green Belts (GBs), Black Belts (BBs), and Master Black Belts (MBBs), who lead teams focused on projects that have both quality and business (economic) impacts for the organization. The "belts" have specialized training and education on statistical methods and the quality and process improvement tools in this textbook that equips them to function as team leaders, facilitators, and problem solvers.

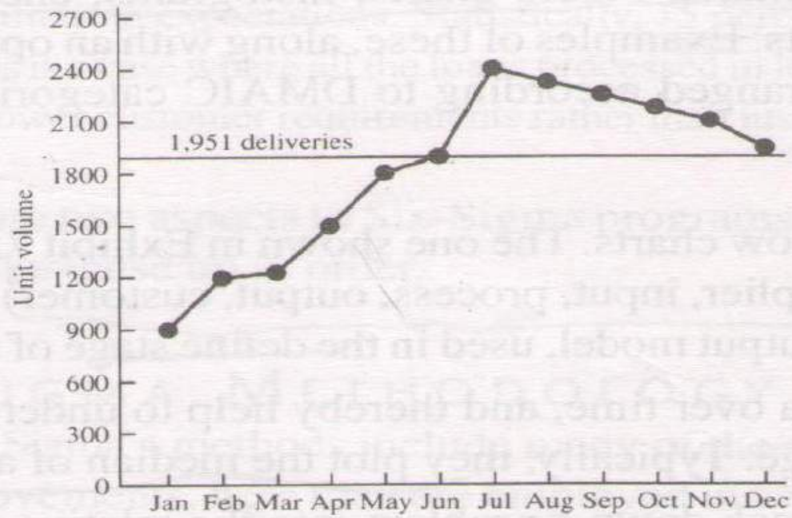
Flow Chart of Major Steps in a Process*



Define

Run Chart**

Average monthly volume of deliveries
(per shop)



Measure

Pareto Chart**

Types of customer complaints
Total = 2520 October—December
(across 6 shops)

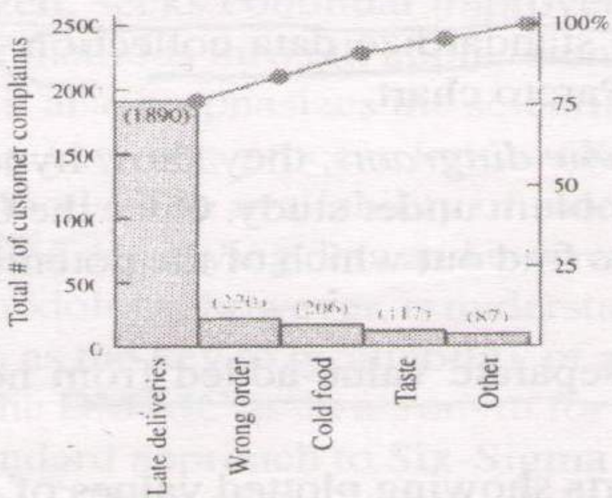
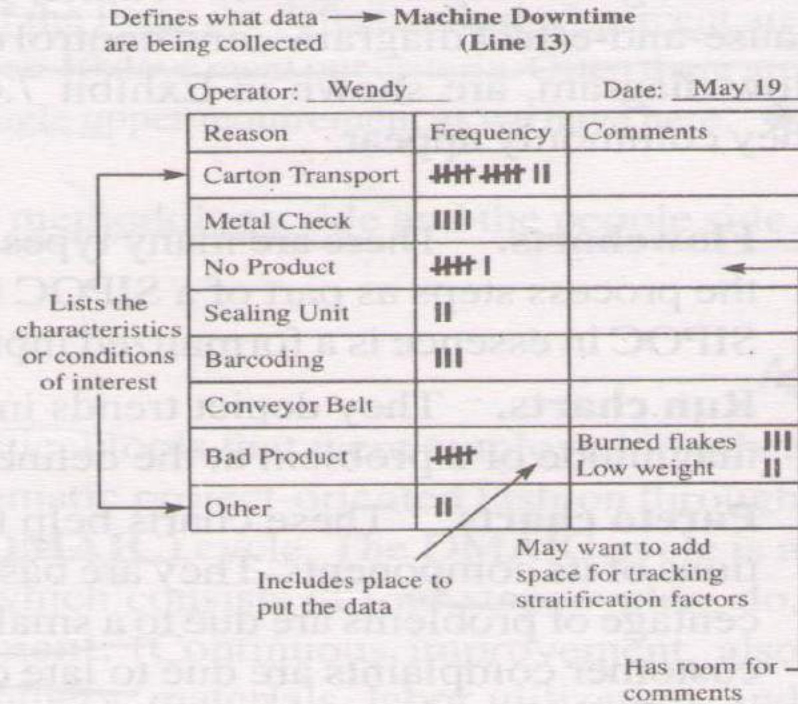


Illustration note: Delivery time was defined by the total time from when the order was placed to when the customer received it.

DATA COLLECTION FORMS*

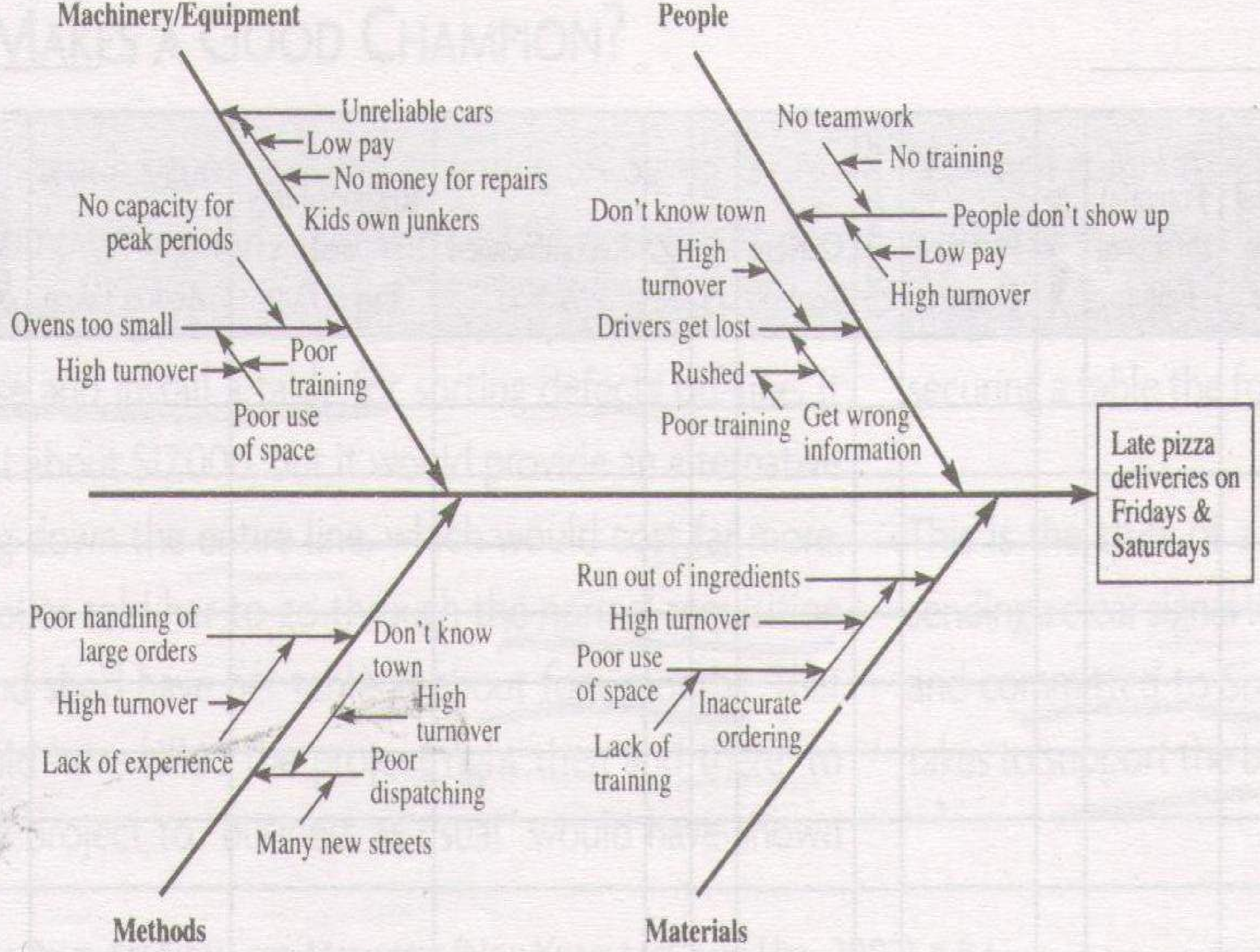
Checksheets are basic forms that help standardize data collection by providing specific spaces where people should record data.



C & E/Fishbone Diagram**

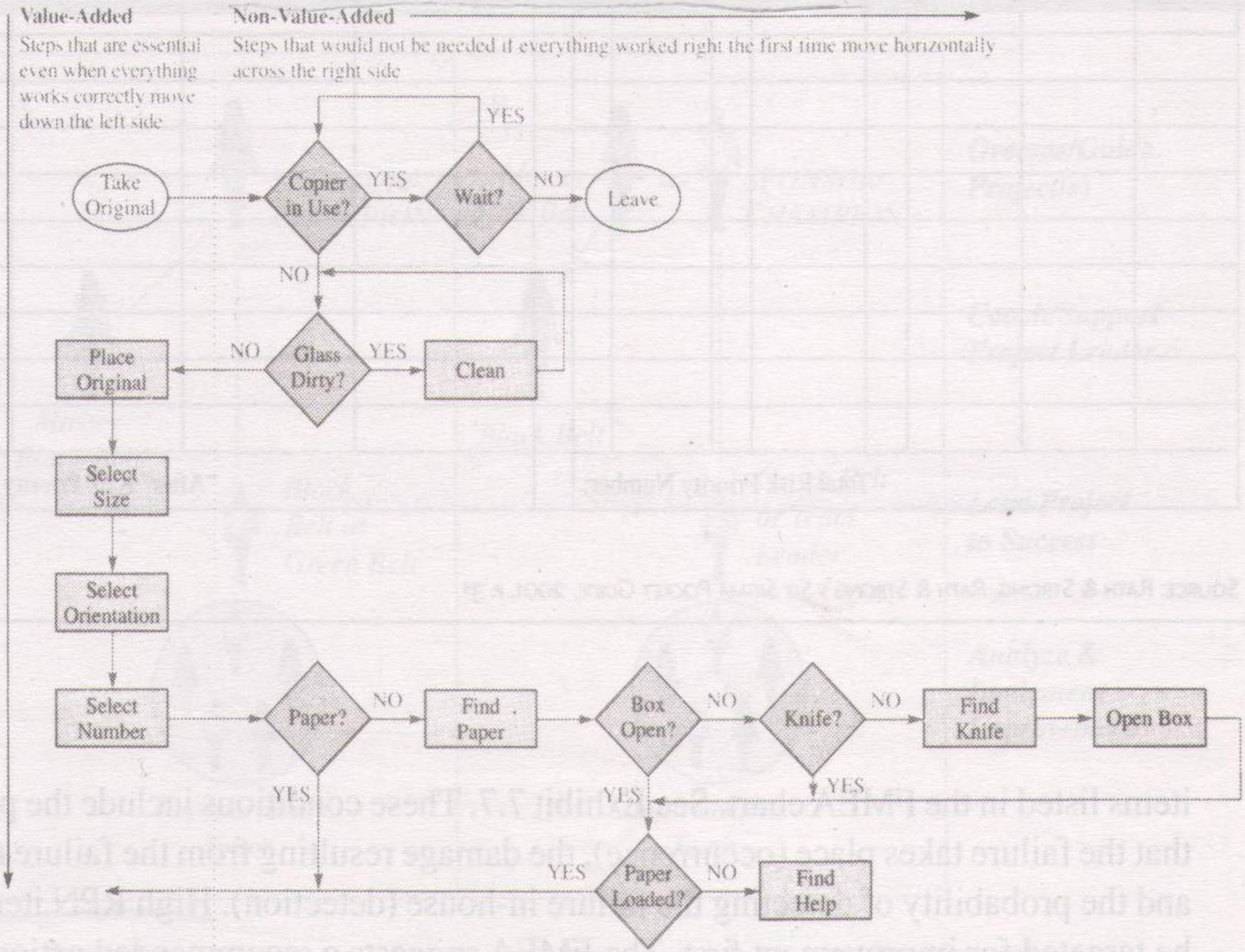
Reasons for late pizza deliveries

Analyze



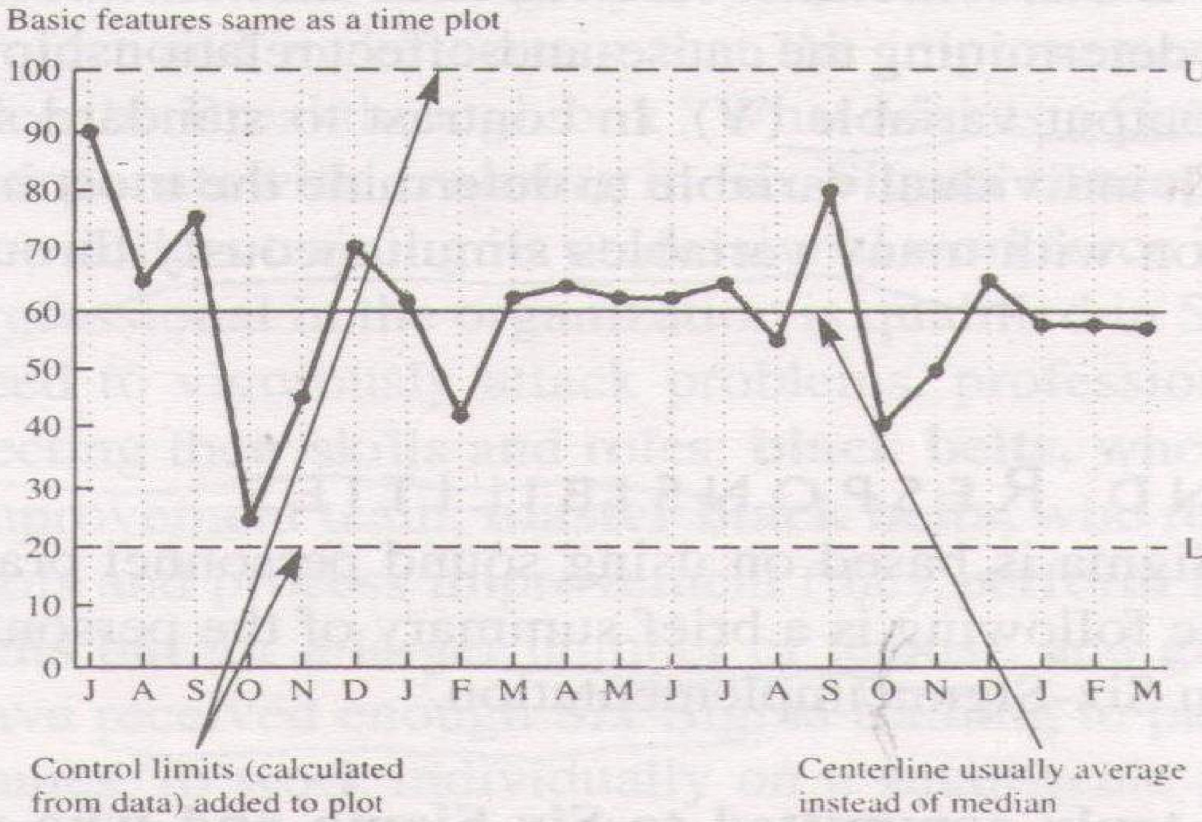
Opportunity Flow Diagram*

Organized to separate value-added steps from non-value-added steps.



Control Chart Features*

Control



Six Sigma (Example)

- Consider the visit to a fast-food restaurant. The customer orders a typical meal: a hamburger bun, meat, special sauce, cheese, pickle, onion, lettuce, and tomato, fries, and a soft drink.

- This product has ten components (independent). Is 99% good quality satisfactory?

P(Single meal good) = (0.99)10 = 0.9044

- Now suppose that the customer is a family of four.

P{All meal good} = (0.9044)4 = 0.6690

- Now suppose that this hypothetical family of four visits this restaurant once a month

P{All visits during the year good} = (0.6690)12 = 0.0080

Generations of Six Sigma

- Since its origins, there have been three generations of six-sigma implementations.
  - **Generation I six-sigma** focused on defect elimination and basic variability reduction. - Motorola
  - In **Generation II six-sigma** the emphasis on variability and defect reduction remained, but now there was a strong effort to tie these efforts to projects and activities that improved business performance through cost reduction. – General Electric
  - In **Generation III, six-sigma** has the additional focus of creating value throughout the organization and for its stakeholders. - Caterpillar and Bank of America

Where can Six Sigma be applied?

- Some examples of situations where a six-sigma program can be applied to reduce variability, eliminate defects, and improve business performance include:
  - Meeting delivery schedule and delivery accuracy targets
  - Eliminating rework in preparing budgets and other financial documents
  - Proportion of repeat visitors to an e-commerce Web site, or proportion of visitors that make a purchase
  - Minimizing cycle time or reducing customer waiting time in any service system
  - Reducing average and variability in days outstanding of accounts receivable
  - Optimizing payment of outstanding accounts
  - Minimizing stock-out or lost sales in supply chain management

Where can Six Sigma be applied?

- Minimizing costs of public accountants, legal services, and other consultants
- Improving inventory management (both finished goods and work in-process)
- Improving forecasting accuracy and timing
- Improving audit processes
- Closing financial books, improving accuracy of journal entry and posting (a 3 to 4% error rate is fairly typical)
- Reducing variability in cash flow
- Improving payroll accuracy
- Improving purchase order accuracy and reducing rework of purchase orders

Six Sigma Organization Structure

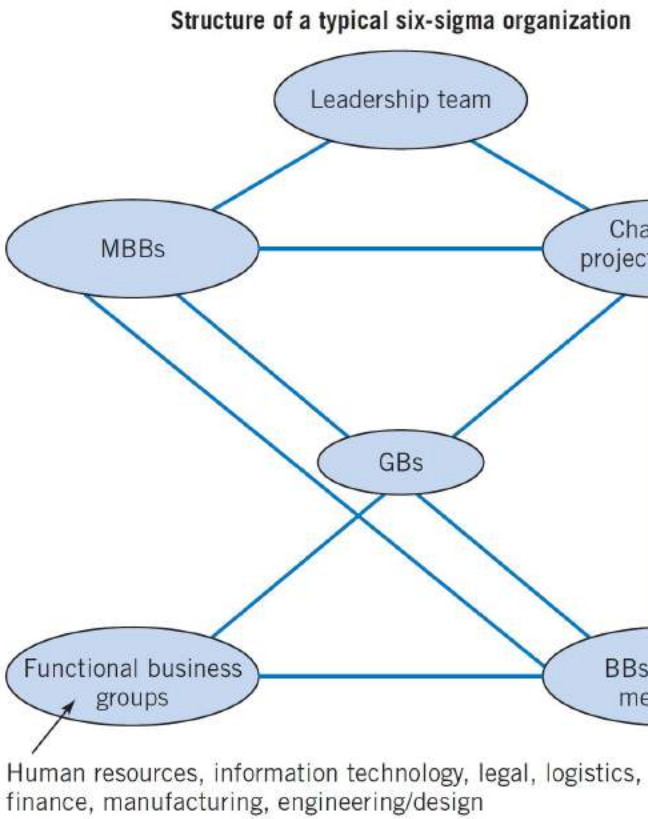


Figure 2.6 The Structure of a Six-Sigma Organization

(Adapted from R. D. Snee and R. W. Hoerl, *Six-Sigma Beyond the Factory Floor,* Upper Saddle River, NJ: Pearson Prentice Hall, 2005).

Beyond Six-Sigma—DFSS and Lean

- In recent years, two other tool sets have become identified with six sigma, lean systems, and design for six-sigma (DFSS).
- Design for Six-Sigma seeks to take customer requirements and process capabilities into consideration to design products and services that increase product and service effectiveness as perceived by the customer.
- DFSS spans the entire development process from the identification of customer needs to the final launch of the new product or service.

DFSS

- Traditionally, six-sigma is used to achieve operational excellence, while DFSS is focused on improving business results by increasing the sales revenue generated from new products and services and finding new applications or opportunities for existing ones.
- An important gain from DFSS is the reduction of development lead time
- The DMAIC process is also applicable, although some organizations and practitioners have slightly different approaches (DMADV, or Define, Measure, Analyze, Design, and Verify, is a popular variation).

DFSS

- An important step in the DFSS process is obtaining customer input.
- Customer input is obtained through **voice of the customer (VOC) activities designed to determine what the customer** really wants, to set priorities based on actual customer wants, and to determine if the business can meet those needs at a competitive price that will enable it to make a profit.
- Some organizations use **Quality Function Deployment or QFD to** focus the voice of the customer directly on the design of a product, service, or process.

QFD

- **Quality Function Deployment is a** technique to transform customer requirements into design quality, down to component level and specific elements of the manufacturing system.
- QFD was developed in Japan in the 1970s.
- An essential component of QFD is the **house of quality.**
- This is essentially a matrix with rows corresponding to customer requirements and columns representing the technical response to these requirements.
- Information about the importance of each requirement and about how well the company's products or services compare to the competition is obtained.
- Analysis of this information leads to directions of improvement in the design of the product or service.

QFD

- It is fairly typical to step this process down from a high level that begins with the voice of the customer data all the way down to individual process steps and the critical-to-process variables that must be controlled to achieve these results.

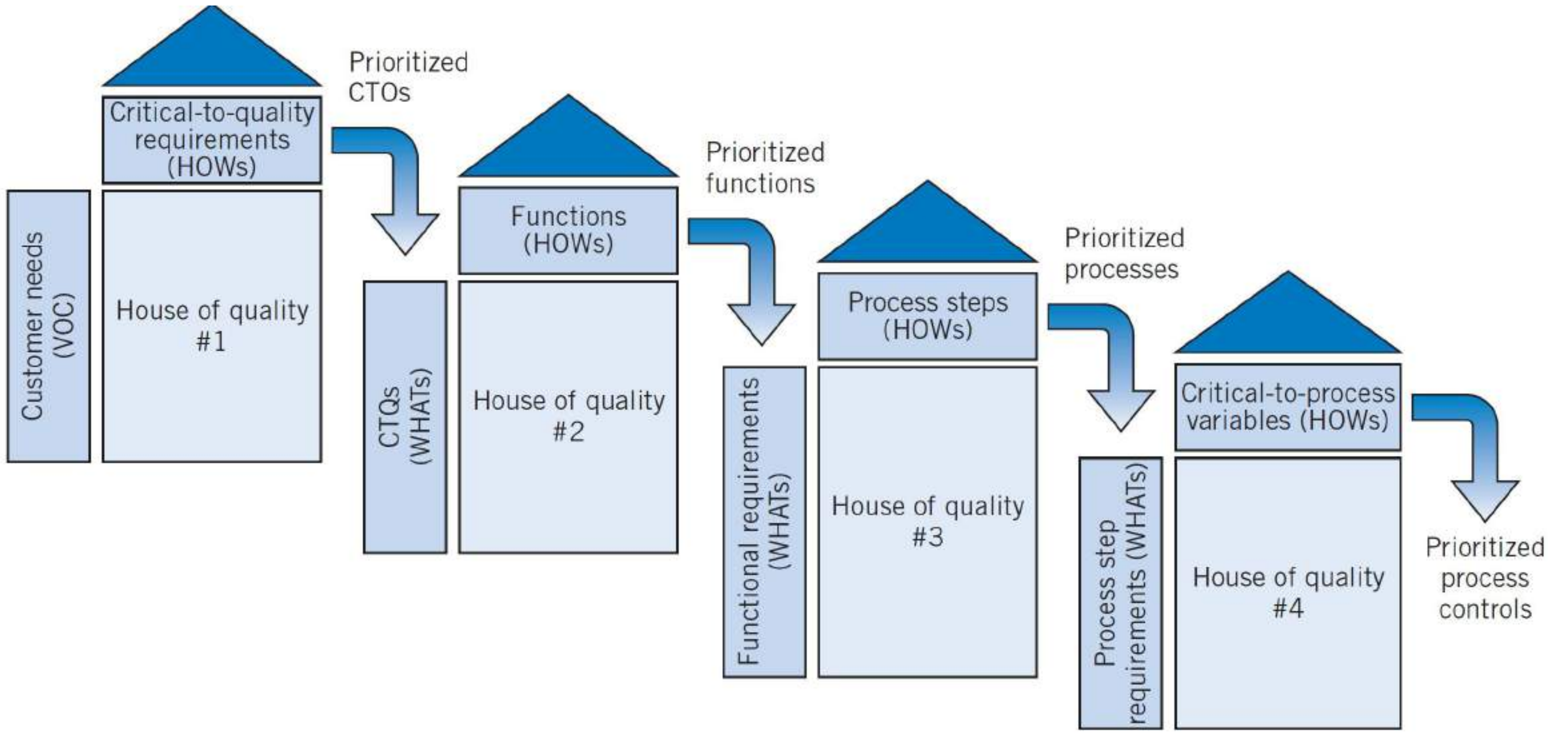
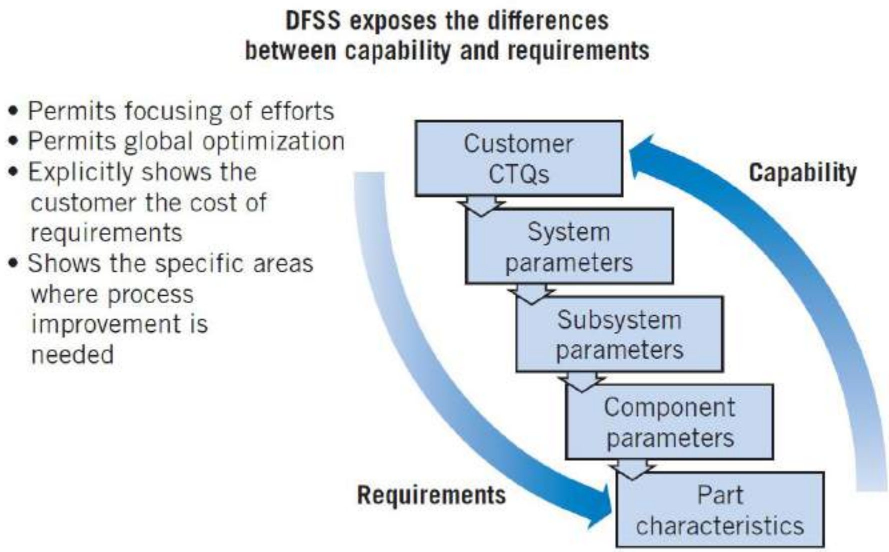


Figure 2.7 A Four-Step Quality Function Deployment Process

DFSS

- DFSS makes specific the recognition that every design decision is a business decision, and that the cost, manufacturability, and performance of the product are determined during design.
- Specifically, matching the capability of the production system and the requirements at each stage or level of the design process (refer to Figure 2.8) is essential.

Figure 2.8 Matching Product Requirements and Production Capability in DFSS



DFSS

- Throughout the DFSS process, it is important that the following points be kept in mind:
  - Is the product concept well identified?
  - Are customers real?
  - Will customers buy this product?
  - Can the company make this product at competitive cost?
  - Are the financial returns acceptable?
  - Does this product fit with the overall business strategy?
  - Is the risk assessment acceptable?
  - Can the company make this product better than the competition?
  - Can product reliability and maintainability goals be met?
  - Has a plan for transfer to manufacturing been developed and verified?

Lean

- Lean is a series of practices that focus on the systematic elimination of waste and the promotion of efficiency.
- Waste can also include rework of doing something over again to eliminate defects introduced the first time) or scrap.
- Rework and scrap are often the result of excess variability, so there is an obvious connection between six-sigma and lean. An important metric in lean is the process cycle efficiency PCE), defined as

  Process cycle efficiency = Value-add time/Process cycle time

- In a lean process, the PCE will exceed 25%

Lean

- Process cycle time is also related to the amount of work that is in-process through **Little's Law**

  Process cycle time = Work-in-process / Average completion rate

- Example:
  - Consider a mortgage refinance operation at a bank.
  - If the average completion rate for submitted applications is 100 completions per day, then there are 1,500 applications waiting for processing.
  - The process cycle time = 1500/100 = 15 days

Lean Tools

- One of the most important tools used in Lean is discrete event simulation, in which a computer model of the system is built and used to quantify the impact of changes to the system that improve its performance.
- Other commonly used lean tools are:

• **Value-stream and value-added process mapping**	A graphical approach to describing the important material and information flows in the process. Process mapping is described in detail in Chapter 3.
• **The five Ss**	These principles focus on creating orderliness and discipline in the workplace: Separate, Straighten, Scrub, Standardize, and Systematize.
• **Kanban**	Pull inventory management; that is, don't produce parts until they are needed. In the early days a kanban was a piece of paper or a card that ordered the production of a part. Today it is most likely a computer record.

Lean Tools (contd.)

• **Error-proofing (or Poka-Yoke)**	Designing work or products so that it is nearly impossible to do the work incorrectly. This can include color-coding components so that they are assembled correctly, constructing visual aids for workers so that they can see what the finished item should look like, or designing components so that they can only be assembled one way. Special error-checking or control devices that provide feedback to operators when work is not correctly performed, such as feedback from a computer program when a required field is blank or not filled out in the expected format, are also examples of error-proofing.
• **Set-up time reduction and reduced lot sizes**	A process of identifying waste and inefficiencies in the process of changing over tools and equipment from one product to another and then eliminating this wasted effort. Lengthy changeovers and setups limit the flexibility of an organization to respond quickly to customer needs and also contribute to large lot sizes. Ideally, one should aim for a single minute exchange of dies (SMED). Considerable reduction in setup times can often be achieved by reorganizing the work process surrounding changeovers and by redesigning the tools and dies themselves to facilitate rapid setups. Large lot sizes result in excess inventory (and dollars tied up in inventory), excess handling of materials, larger space requirements, risk of obsolesce, and risk of damage or spoilage. When setup times are short, lot sizes can also be small.

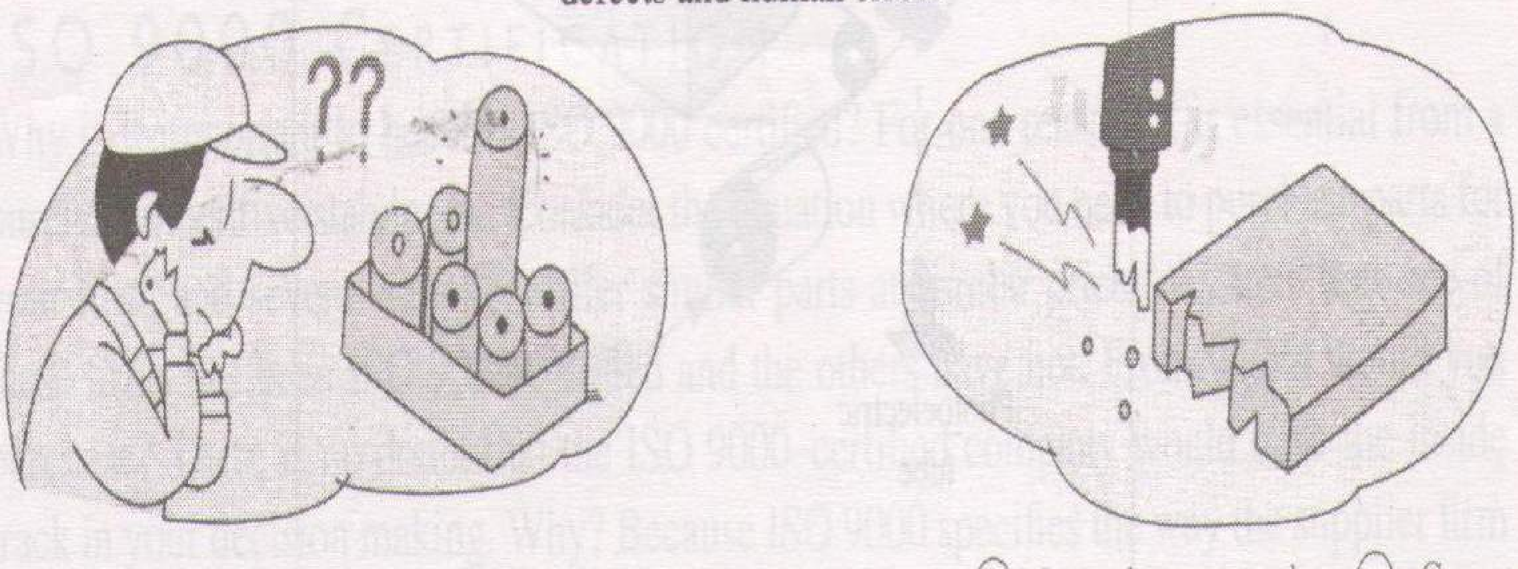
What Are the Sources of Defects?

There are various types of defects. In order of importance these are

1. Omitted processing
2. Processing errors
3. Errors setting up workpieces
4. Missing parts
5. Wrong parts
6. Processing wrong workpiece
7. Misoperation
8. Adjustment error
9. Equipment not set up properly
10. Tools and jigs improperly prepared

What are the connections between these defects and the mistakes people make?

☆ Causal connections between defects and human errors



⊙ Strongly connected ○ Connected

Human Errors / Causes of Defects	Intentional	Mis-understanding	Forgetful	Mis-identification	Amateurs	Willfull	Inadvertent	Slowness	Non-supervision	Surprise
Omitted processing	⊙	○	⊙	○	○	○	⊙	○	○	
Processing errors	⊙	⊙	○	○	⊙	⊙	⊙	⊙	⊙	
Errors setting up workpieces	○	○	⊙	○	○		⊙	○	○	
Missing parts	⊙	○	○		○	○	⊙		○	
Wrong parts	⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	
Processing wrong workpiece	○	⊙	⊙	○	○	⊙	⊙		○	
Misoperation			○				○		○	⊙
Adjustment error	○	○	○	⊙	○	⊙	○	○	○	○
Improper equipment setup			○				○			⊙
Improper tools and jigs			○				○			○

Source: N. K. Shimbun, Ltd./Factory Magazine (ed.), *Poka-Yoke: Improving Product Quality by Preventing Defects* (Cambridge, MA: Productivity Press, 1989), p. 14. From *POKA-YOKE: Improving Product Quality by Preventing Defects*, edited by NKS/Factory Magazine.

- **Poka-Yoke includes:**
    - **Checklists**
    - **Special tooling that prevents workers from making errors**

FMEA

- Severity

  Importance of the effect on customer requirements

  Often can't do anything about this

- Occurrence
  - Frequency with which a given cause occurs and creates failure modes
- Detection
  - The ability of the current control scheme to detect or prevent a given cause

Risk Priority Number (RPN)

- RPN is the product of the severity, occurrence, and detection scores.

Severity x Occurrence x Detection = RPN

The FMEA Form

A Closer Look

Process/Product
Failure Modes and Effects Analysis Form
(FMEA)

Process or Product Name:		Prepared by:	Page____ of____
Responsible:		FMEA Date (Orig)______________ (Rev)____________	

Process Step / Input	Potential Failure Mode	Potential Failure Effects	SEVERITY	Potential Causes	OCCURRENCE	Current Controls	DETECTION	RPN	Actions Recommended	Resp.	Actions Taken	SEVERITY	OCCURRENCE	DETECTION	RPN
What is the process step and Input under investiga-tion?	In what ways does the Key Input go wrong?	What is the impact on the Key Output Variables (Customer Requirements)?		What causes the Key Input to go wrong?		What are the existing controls and procedures (inspection and test) that prevent either the cause or the Failure Mode?			What are the actions for reducing the occurrence of the cause, or improving detection?		What are the completed actions taken with the recalculated RPN?				
								0							0
								0							0
								0							0
								0							0
								0							0

Identify failure modes and their effects

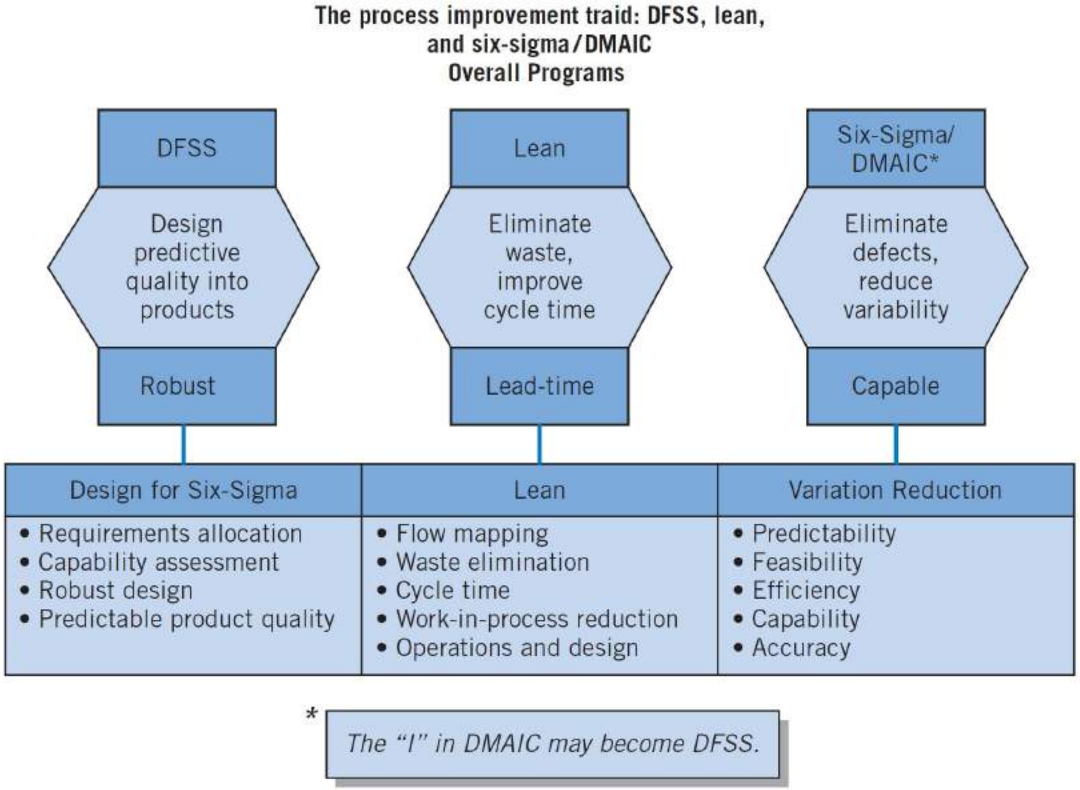
Identify causes of the failure modes and controls

Prioritize

Determine and assess actions

How they fit together?

Figure 2.9 Six-Sigma/DMAIC, Lean, and DFSS: How They Fit Together



Six Sigma, DFSS, Lean

- Six-sigma (often combined with DFSS and lean) has been much more successful than its predecessors, notably TQM.
- The project-by-project approach and the focus on obtaining improvement in bottomline business results has been instrumental in obtaining management commitment to six-sigma.
- Another major component in obtaining success is driving the proper deployment of statistical methods into the right places in the organization.
- The DMAIC problem-solving framework is an important part of this.

Quality Improvement Initiatives

- There have been many initiatives devoted to improving the production system.
  - Some of these include the Just-in-Time approach emphasizing in-process inventory reduction, rapid set-up, and a pull-type production system;
  - Poka-Yoke or mistake-proofing of processes;
  - The Toyota production system and other Japanese manufacturing techniques (with once-popular management books by those names);
  - reengineering;
  - theory of constraints; agile manufacturing; and so on.
- Most of these programs devote far too little attention to variability reduction.

Quality

Learning Objectives

- **Quality:**
  - Definition
  - Dimensions
  - Determinants
  - Cost
  - Impact

What is Quality?

- Conformance to specifications
- Fitness for use
- Value for price paid

- $$Q = P/E$$
- Q = Quality
- P = Performance
- E = Expectations

What is Quality?

“*The quality of a product or service is a customer’s perception of the degree to which the product or service meets his or her expectations.”*

Nature of Quality

- Dimensions of Quality

- Determinants of Quality

- Costs of Quality

Some Dimensions of Product Quality

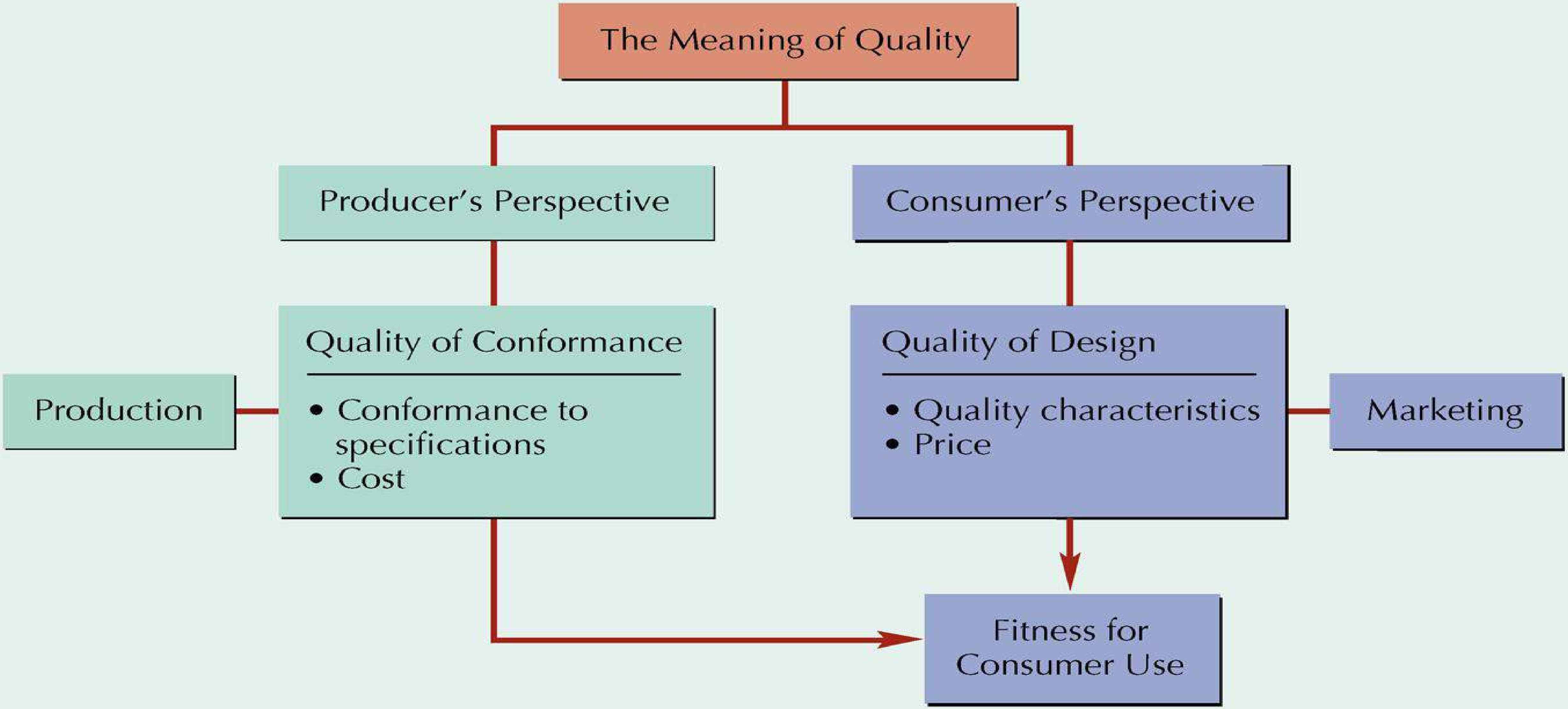
- Performance – primary characteristics (signal to noise ratio, power - time to process customer requests)
- Features – secondary characteristics, special characteristics (remote control)
- Reliability – Consistency of performance over time. (MTTF,MTBF,breakdowns, malfunctions)
- Serviceability – Ease of repair. (speed/cost/convenience of servicing)

- Durability – useful life amount of time/use before repairs

- Appearance – aesthetics, effects on human senses

- Customer service – treatment before/during/after sale

- Safety – user protection before/during/after use


The Meaning of Quality
Producer's Perspective
Consumer's Perspective
Production
Quality of Conformance
• Conformance to specifications
• Cost
Quality of Design
• Quality characteristics
• Price
Marketing
Fitness for Consumer Use

- Customer’s and producer’s perspectives depend on each other
- Producer’s perspective:
  - production process and COST
- Customer’s perspective:
  - fitness for use and PRICE
- Customer’s view must dominate

Learning Objectives

- **Quality:**
    - Definition
    - Dimensions
    - **Determinants**
    - **Cost**
    - Impact

Determinants of Quality

- Quality of design – products/service designed based on customers’ expectations and desires.
- Quality capability of production processes – processes must be capable of producing the products designed for the customers (surface finish in microns : m/cs. Tools. Measuring equipment)
- Quality of conformance – refers to the degree to which the product or service design specifications are met. (capable processes can produce inferior product if not operated properly.
- Quality of customer service – a superior product does not mean success; must have quality service also
- Organization quality culture – superior product and service requires organization-wide focus on quality

Costs of Quality

- <u>Scrap and rework</u> - rescheduling, repairing, retesting
- <u>Defective products in the hands of the customer</u> - recalls, warranty claims, due to awareness - law suits, lost business, …
- <u>Detecting defects</u> - inspection, testing, ….
- <u>Preventing defects</u> - training, charting performance,
- Product/process redesign, supplier development, ….

Cost of Quality

- Cost of Achieving Good Quality
  - Prevention costs
    - costs incurred during product design
  - Appraisal costs
    - costs of measuring, testing, and analyzing
- Cost of Poor Quality
  - Internal failure costs
    - include scrap, rework, process failure, downtime, and price reductions
  - External failure costs
    - include complaints, returns, warranty claims, liability, and lost sales

Prevention Costs

- Quality planning costs
  - costs of developing and implementing quality management program
- Product-design costs
  - costs of designing products with quality characteristics
- Process costs
  - costs expended to make sure productive process conforms to quality specifications
- Training costs
  - costs of developing and putting on quality training programs for employees and management
- Information costs
  - costs of acquiring and maintaining data related to quality, and development and analysis of reports on quality performance

Appraisal Costs

- Inspection and testing
  - costs of testing and inspecting materials, parts, and product at various stages and at end of process
- Test equipment costs
  - costs of maintaining equipment used in testing quality characteristics of products
- Operator costs
  - costs of time spent by operators to gather data for testing product quality, to make equipment adjustments to maintain quality, and to stop work to assess quality

Internal Failure Costs

- Scrap costs
  - costs of poor-quality products that must be discarded, including labor, material, and indirect costs
- Rework costs
  - costs of fixing defective products to conform to quality specifications
- Process failure costs
  - costs of determining why production process is producing poor-quality products
- Process downtime costs
  - costs of shutting down productive process to fix problem
- Price-downgrading costs
  - costs of discounting poor-quality products—that is, selling products as "seconds"

External Failure Costs

- Customer complaint costs
  - costs of investigating and satisfactorily responding to a customer complaint resulting from a poor-quality product
- Product return costs
  - costs of handling and replacing poor-quality products returned by customer
- Warranty claims costs
  - costs of complying with product warranties
- Product liability costs
  - litigation costs resulting from product liability and customer injury
- Lost sales costs
  - costs incurred because customers are dissatisfied with poor-quality products and do not make additional purchases

Analysis and Use of Quality Costs (example)

Table 1.3

Monthly Quality-Costs Information for Assembly of Printed Circuit Boards

Type of Defect	Percent of Total Defects	Scrap and Rework Costs
Insufficient solder	42	$37,500.00 (52%)
Misaligned components	21	12,000.00
Defective components	15	8,000.00
Missing components	10	5,100.00
Cold solder joints	7	5,000.00
All other causes	5	4,600.00
Totals	100%	$72,200.00

Quality Costs

- **Leverage Effect –**money invested in prevention and appraisal have a payoff in reducing dollars incurred in internal and external failures that exceeds the original investment.

- **Pareto Analysis** - Consists of identifying quality costs by category, or by product, or by type of defect or nonconformity.

- **Reducing the cost of quality** - Most of the cost reductions will come from attacking the few problems that are responsible for the majority of quality costs.

Quality Costs

- Generating quality cost information
  - The organization's accounting system can provide information on those quality-cost categories that coincide with the usual business accounts
  - Information for cost categories for which exact accounting information is not available should be generated by using estimates

- The usual method of reporting quality costs is in the form of a ratio in which the numerator is quality cost dollars and the denominator is some measure of activity

- Upper Management may want a standard to compare against and this is usually done by comparing current performance to past performance

Measuring and Reporting Quality Costs

- Index numbers
  - ratios that measure quality costs against a base value
  - labor index
    - ratio of quality cost to labor hours
  - cost index
    - ratio of quality cost to manufacturing cost
  - sales index
    - ratio of quality cost to sales
  - production index
    - ratio of quality cost to units of final product

Cost of Quality

	Year			
	2009	2010	2011	2012
Quality Costs				
Prevention	27,000	41,500	74,600	112,300
Appraisal	155,000	122,500	113,400	107,000
Internal failure	386,400	469,200	347,800	219,100
External failure	242,000	196,000	103,500	106,000
Total	810,400	829,200	639,300	544,400
Accounting Measures				
Sales	4,360,000	4,450,000	5,050,000	5,190,000
Manufacturing costs	1,760,000	1,810,000	1,880,000	1,890,000

Cost of Quality

Quality index = total quality costs/base * 100

2009 quality cost per sale

810,400 * 100 / 4,360,000 = 18.58

Year	Quality Sales Index	Quality Manufacturing Cost Index
2009	18.58	46.04
2010	18.63	45.18
2011	12.66	34.00
2012	10.49	28.80

Quality–Cost Relationship

- Cost of quality
  - difference between price of nonconformance and conformance
  - cost of doing things wrong
    - 20 to 35% of revenues
  - cost of doing things right
    - 3 to 4% of revenues

Failure of quality cost initiatives

- There are several reasons for the failure of quality-cost collection and analysis efforts
  - Failure to use quality-cost information as a mechanism for generating improvement opportunities
  - Overemphasis in treating quality costs as part of the accounting systems rather than as a management control tool
  - Management often underestimates the depth and extent of the commitment to prevention that must be made.

Legal Aspects of Quality

- Consumerism and product liability are important reasons why quality assurance is an important business strategy.

- Virtually every product line of today is superior to that of yesterday. Consumer dissatisfaction and the general feeling that today's products are inferior to their predecessors arise from other phenomena.

  – **Explosion** in the number of products
  – **Consumer tolerance** for minor defects and aesthetic problems has decreased considerably, so that blemishes, surface-finish defects, noises, and appearance problems that were once tolerated now attract attention and result in adverse consumer reaction.
  – **Competitiveness** of the marketplace forces many manufacturers to introduce new designs before they are fully evaluated and tested in order to remain competitive.

Legal Aspects of Quality

- Product liability is a major social, market, and economic force.
- In recent years, the courts have placed a more stringent rule in effect called strict liability. Two principles are characteristic of strict liability.
  - The first is a strong responsibility for both manufacturer and merchandiser, requiring immediate responsiveness to unsatisfactory quality through product service, repair, or replacement of defective Product.
  - Under strict product liability all advertising statements must be supportable by valid company quality or certification data, comparable to that now maintained for product identification under regulations for such products as automobiles.

Implementing Quality Improvement

- A critical part of the strategic management of quality within any business is the recognition of these dimensions by management and the selection of dimensions along which the business will compete.

- It is not necessary for the product to be superior in all dimensions of quality, but management must select and develop the "niches" of quality along which the company can successfully compete.

- **Supplier selection and supply chain management** may be the most critical aspects of successful quality management in industries such as automotive, aerospace, and electronics, where a very high percentage of the parts in the end item are manufactured by outside suppliers.

Implementing Quality Improvement

- It is critical that management recognize that quality improvement must be a total, company-wide activity, and that every organizational unit must actively participate.

- The quality assurance function is a technology warehouse that contains the skills and resources necessary to generate products of acceptable quality in the marketplace.

- The quality function is not responsible for quality. The responsibility for quality is distributed throughout the entire organization.

Implementing Quality Improvement

- Strategic management of quality in an organization must involve all three components discussed earlier: quality planning, quality assurance, and quality control and improvement.

- *All* of the individuals in the organization must have an understanding of the basic tools of quality improvement.

- The key point is the philosophy that statistical methodology is a language of communication about problems that enables management to mobilize resources rapidly and to efficiently develop solutions to such problems.

Learning Objectives

- **Quality:**
  - Definition
  - Dimensions
  - Determinants
  - Cost
  - **Impact**

Do O&SCM and QM practices create an impact?

- Impact on the
  - Organization
  - Customers
  - Society

Effect of Quality Management on Productivity

- Productivity = output / input
- Quality impact on productivity
  - fewer defects increase output, and quality improvement reduces inputs
- Yield
  - a measure of productivity

Manufacturing Example

- Consider the manufacture of a mechanical component used in a copier machine.
- Parts are manufactured in a machining process at a rate of approximately 100 parts per day.
  - First-pass yield = 75% (conforming).
  - 60% of the fallout (the 25% nonconforming) can be reworked into an acceptable product, and the rest must be scrapped.
- The direct manufacturing cost = $20/part.
- Reworked parts incur an additional processing charge = $4

  Cost / good part = (($20*100) + ($4*15))/90 = $22.89

  Total Yield after rework = 90 good parts / day

Manufacturing Example

- Statistical process control procedure reduces variability and thereby process fallout from 25% to 5%.
  - Of the 5% fallout produced, about 60% can be reworked & 40% are scrapped

    Cost / good part = (($20*100) + ($4*3))/98 = $20.53

    Total Yield after rework = 98 good parts / day
- Installation of statistical process control & the reduction of variability led to
  - 10.3% reduction in manufacturing costs
  - 10% increase in productivity

Measuring Product Yield and Productivity

Yield=(total input)(% good units) + (total input)(1-%good units)(% reworked)

or

$$Y=(I)(\%G)+(I)(1-\%G)(\%R)$$

where

I = initial quantity started in production

%G = percentage of good units produced

%R = percentage of defective units that are successfully reworked

Computing Product Yield

- Motor manufacturer
- Starts a batch of 100 motors.
- 80 % are good when produced
- 50 % of the defective motors can be reworked

$Y = (I)(\%G)+(I)(1-\%G)(\%R)$

$=$

Increase quality to 90% good

$Y =$

Computing Product Yield

- Motor manufacturer
- Starts a batch of 100 motors.
- 80 % are good when produced
- 50 % of the defective motors can be reworked

Y =(I)(%G)+(I)(1-%G)(%R)

= 100(.80) + 100(1-.80)(.50) = 90 motors

Increase quality to 90% good

Y =100(.90) + 100(1-.90)(.50) = 95 motors

Computing Product Cost per Unit

$$\text{Product Cost} = \frac{(K_d)(I) + (K_r)(R)}{Y}$$

where:
K_d = direct manufacturing cost per unit
I = input
K_r = rework cost per unit
R = reworked units
Y = yield

Cost per Unit

Direct cost = $30

80% good

Rework cost = $12

50% can be reworked

$$\frac{(K_d)(I)+(K_r)(R)}{Y} =$$

Increase quality to 90% good

Cost per Unit

Direct cost = \$30

80% good

Rework cost = \$12

50% can be reworked

$$\frac{(K_d)(I)+(K_r)(R)}{Y} = \frac{\$30*100 + \$12*10}{90 \text{ motors}} = \$34.67/\text{motor}$$

Increase quality to 90% good

$$= \frac{\$30*100 + \$12*5}{95 \text{ motors}} = \$32.21/\text{motor}$$

Computing Product Yield for Multistage Processes

$$Y = (I)(\%g_1)(\%g_2) \ldots (\%g_n)$$

where:
I = input of items to the production process that will result in finished products
g_i = good-quality, work-in-process products at stage i

Multistage Yield

Stage	Average Percentage Good Quality
1	0.93
2	0.95
3	0.97
4	0.92

$$Y = (I)(\%g_1)(\%g_2)\ \ldots\ (\%g_n)$$

Multistage Yield

Stage	Average Percentage Good Quality
1	0.93
2	0.95
3	0.97
4	0.92

$$Y = (I)(\%g_1)(\%g_2)\ \ldots\ (\%g_n)$$

$$= 100 * .93 * .95 * .97 * .92 = 78.8 \text{ motors}$$

Initial Batch Size For 100 Motors

$$I = \frac{Y}{(\%g_1)(\%g_2)\ \ldots\ (\%g_n)}$$

Initial Batch Size For 100 Motors

$$I = \frac{Y}{(\%g_1)(\%g_2)\ \ldots\ (\%g_n)}$$

$$= \frac{\mathit{100}}{100 * .93 * .95 * .97 * .92} = 126.88 \rightarrow 127$$

Quality–Productivity Ratio

QPR

– productivity index that includes productivity and quality costs

$$\text{QPR} = \frac{(\text{good-quality units})}{(\text{input})\,(\text{processing cost}) + (\text{reworked units})\,(\text{rework cost})}(100)$$

Quality Productivity Ratio

Direct cost = $30

80% good

Initial batch size = 100

Rework cost = $12

50% can be reworked

Base Case

QPR =

Case 1: Increase I to 200

QPR =

Quality Productivity Ratio

Case 2: Reduce direct cost to $26 and rework cost to $10

QPR =

Case 3: Increase %G to 95%

QPR =

Case 4: Decrease costs and increase %G

QPR =

Quality Productivity Ratio

Direct cost = $30

80% good

Initial batch size = 100

Rework cost = $12

50% can be reworked

Base Case

$$QPR = \frac{80 + 10}{100 * \$30 + 10 * \$12} (100) = 2.89$$

Case 1: Increase I to 200

$$QPR = \frac{160 + 20}{200 * \$30 + 20 * \$12} (100) = 2.89 \text{ – NO CHANGE}$$

Quality Productivity Ratio

Case 2: Reduce direct cost to $26 and rework cost to $10

$$QPR = \frac{80 + 10}{100 * \$26 + 10 * \$10} (100) = 3.33$$

Case 3: Increase %G to 95%

$$QPR = \frac{95 + 2.5}{100 * \$30 + 2.5 * \$12} (100) = 3.22$$

Case 4: Decrease costs and increase %G

$$QPR = \frac{95 + 2.5}{100 * \$26 + 2.5 * \$10} (100) = 3.71$$

Statistical Process Control

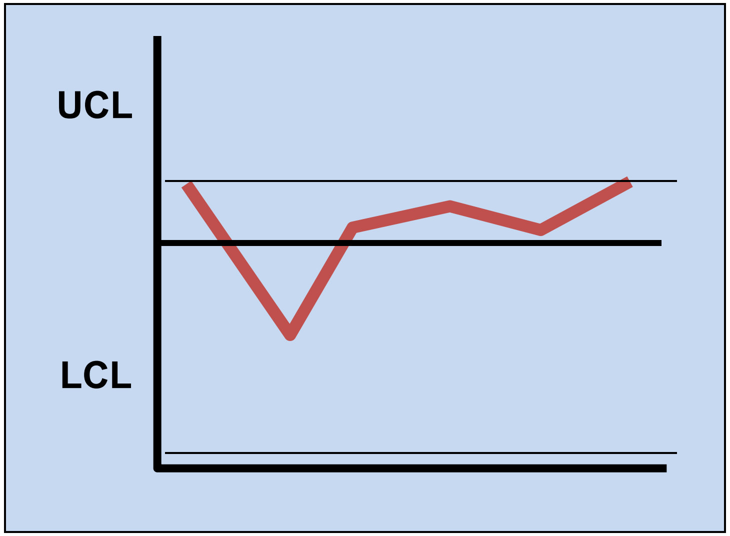
Lecture Outline

Learning Objectives

- Explain when and how to use statistical process control to ensure the quality of products and services
- Discuss the rationale and procedure for constructing attribute and variable control charts
- Utilize appropriate control charts to determine if a process is in-control
- Identify control chart patterns and describe appropriate data collection
- Assess the process capability of a process

Statistical Process Control (SPC)

- Statistical Process Control
  - monitoring production process to detect and prevent poor quality
- Sample
  - subset of items produced to use for inspection
- Control Charts
  - process is within statistical control limits



Process Variability

- <u>Random</u>
  - inherent in a process
  - depends on equipment and machinery, engineering, operator, and system of measurement
  - natural occurrences
- <u>Non-Random</u>
  - special causes
  - identifiable and correctable
  - include equipment out of adjustment, defective materials, changes in parts or materials, broken machinery or equipment, operator fatigue or poor work methods, or errors due to lack of training

SPC in Quality Management

- SPC uses
  - Is the process in control?
  - Identify problems in order to make improvements
  - Contribute to the TQM goal of continuous improvement

Quality Measures: Attributes and Variables

- Attribute
  - A characteristic which is evaluated with a discrete response
  - good/bad; yes/no; correct/incorrect
- Variable measure
  - A characteristic that is continuous and can be measured
  - Weight, length, voltage, volume

SPC Applied to Services

- Nature of defects is different in services
- Service defect is a failure to meet customer requirements
- Monitor time and customer satisfaction

SPC Applied to Services

- Hospitals
  - timeliness & quickness of care, staff responses to requests, accuracy of lab tests, cleanliness, courtesy, accuracy of paperwork, speed of admittance & checkouts
- Grocery stores
  - waiting time to check out, frequency of out-of-stock items, quality of food items, cleanliness, customer complaints, checkout register errors
- Airlines
  - flight delays, lost luggage & luggage handling, waiting time at ticket counters & check-in, agent & flight attendant courtesy, accurate flight information, cabin cleanliness & maintenance

SPC Applied to Services

- Fast-food restaurants
  - waiting time for service, customer complaints, cleanliness, food quality, order accuracy, employee courtesy
- Catalogue-order companies
  - order accuracy, operator knowledge & courtesy, packaging, delivery time, phone order waiting time
- Insurance companies
  - billing accuracy, timeliness of claims processing, agent availability & response time

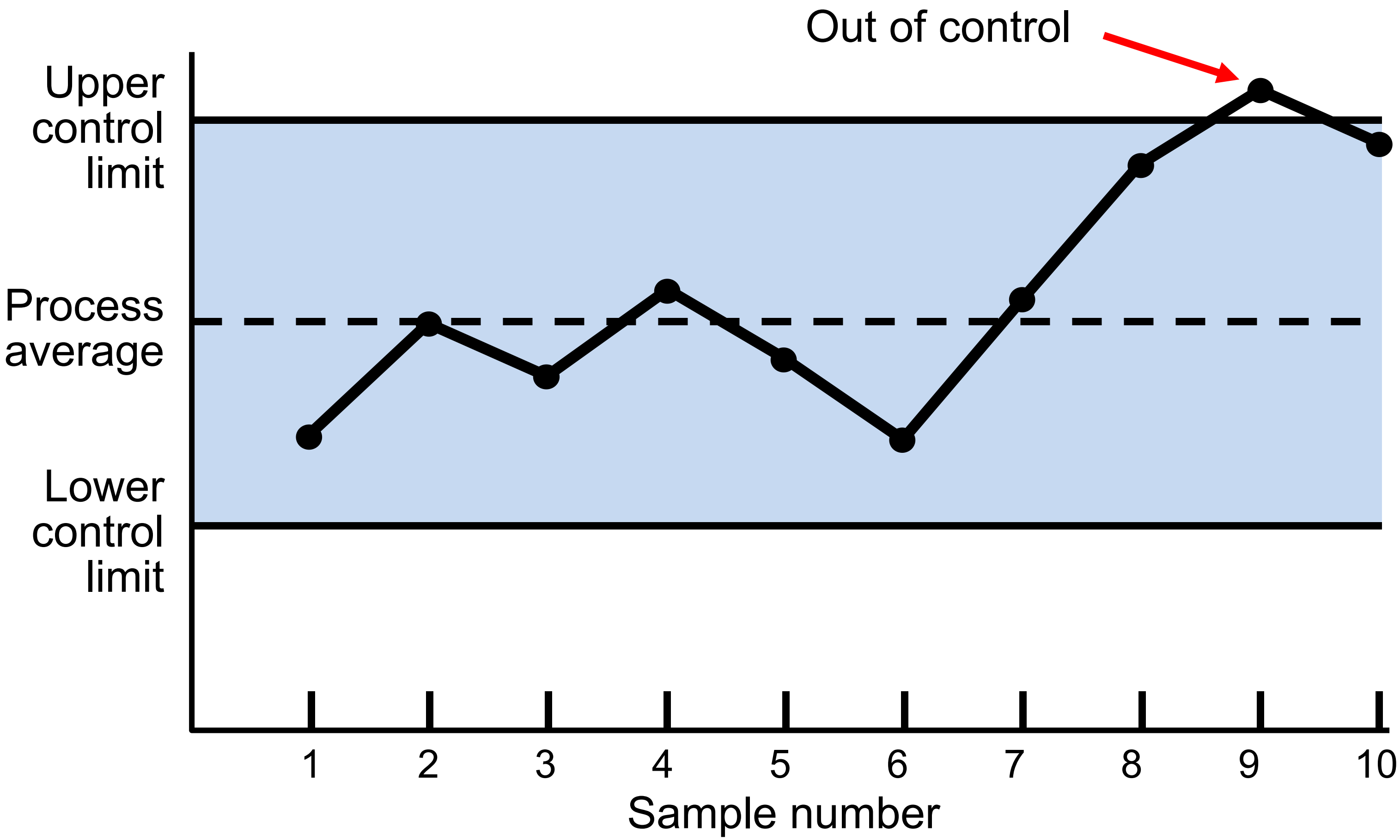
Where to Use Control Charts

- Process
  - Has a tendency to go out of control
  - Is particularly harmful and costly if it goes out of control
- Examples
  - At beginning of process because of waste to begin production process with bad supplies
  - Before a costly or irreversible point, after which product is difficult to rework or correct
  - Before and after assembly or painting operations that might cover defects
  - Before the outgoing final product or service is delivered

Control Charts

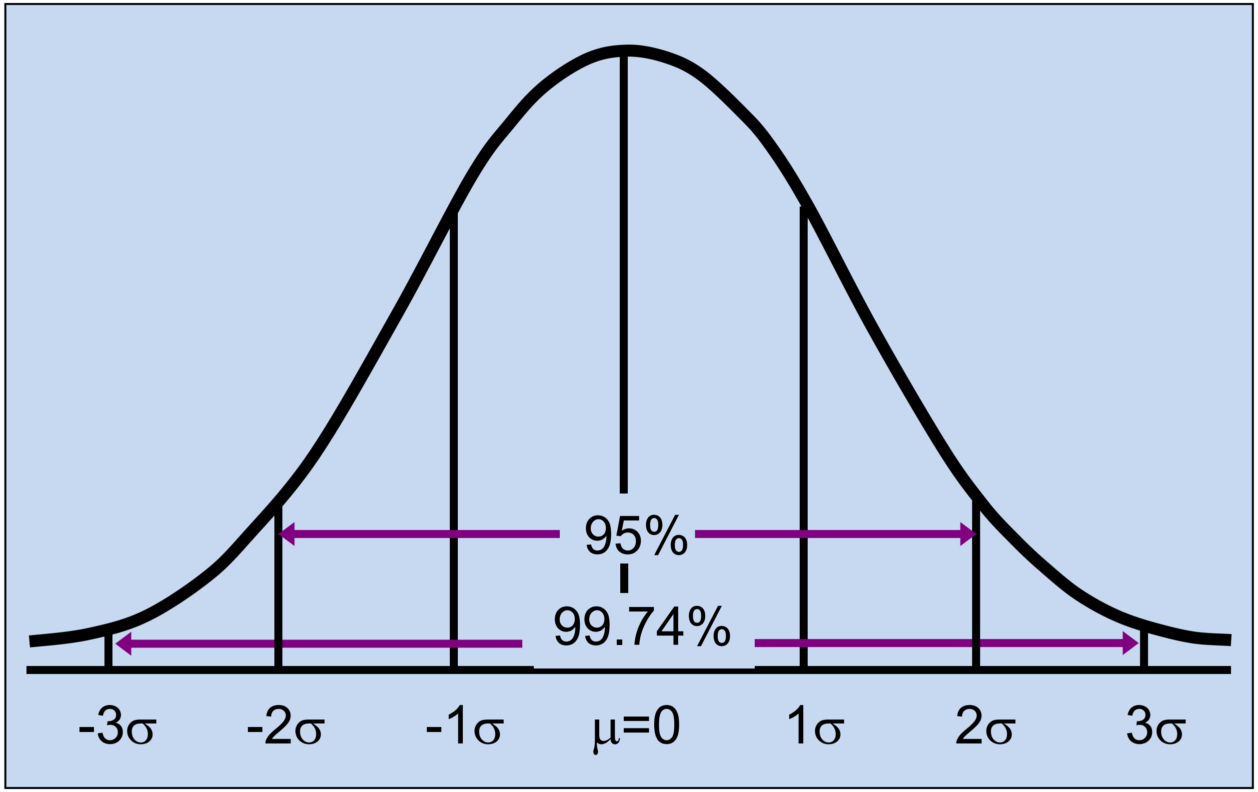
- A graph that monitors process quality
- Control limits
  - upper and lower bands of a control chart
- Attributes chart
  - p-chart
  - c-chart
- Variables chart
  - mean (x bar – chart)
  - range (R-chart)

Process Control Chart



Normal Distribution

- Probabilities for Z= 2.00 and Z = 3.00



A Process Is in Control If …

1. … no sample points outside limits
2. … most points near process average
3. … about equal number of points above and below centerline
4. … points appear randomly distributed

Control Charts for Attributes

- p-chart
  - uses portion defective in a sample
- c-chart
  - uses number of defects (non-conformities) in a sample

p-Chart

$$UCL = \bar{p} + z\sigma_p$$

$$LCL = \bar{p} - z\sigma_p$$

z = number of standard deviations from process average

$\bar{p}$ = sample proportion defective; estimates process mean

σ_p = standard deviation of sample proportion

$$\sigma_p = \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$

Construction of p-Chart

SAMPLE #	NUMBER OF DEFECTIVES	PROPORTION DEFECTIVE
1	6	.06
2	0	.00
3	4	.04
:	:	:
:	:	:
20	18	.18
	200	

20 samples of 100 pairs of jeans

Construction of p-Chart

$$\bar{p} = \frac{\text{total defectives}}{\text{total sample observations}} =$$

$$\text{UCL} = \bar{p} + z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} =$$

UCL =

$$\text{LCL} = \bar{p} - z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} =$$

LCL =

Construction of p-Chart

$$\bar{p} = \frac{\text{total defectives}}{\text{total sample observations}} = 200 / 20(100) = 0.10$$

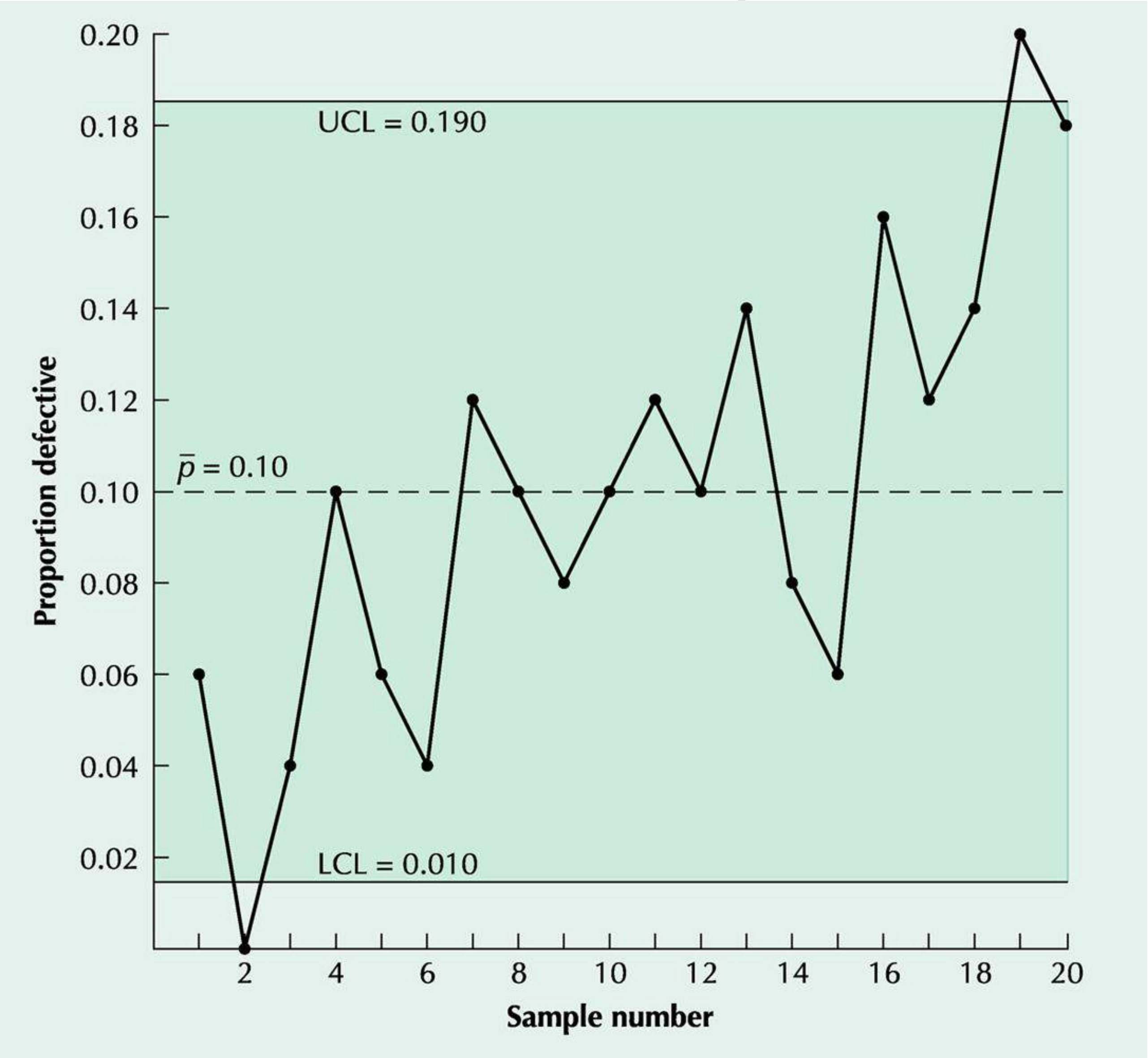
$$UCL = \bar{p} + z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} = 0.10 + 3\sqrt{\frac{0.10(1 - 0.10)}{100}}$$

$$UCL = 0.190$$

$$LCL = \bar{p} - z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} = 0.10 - 3\sqrt{\frac{0.10(1 - 0.10)}{100}}$$

$$LCL = 0.010$$

Construction of p-Chart



p-Chart in Excel

Exhibit3.1.SPC [Compatibility Mode] - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Add-Ins

Click on “Insert” then “Charts” to construct control chart

Example 3.1. Construction of a *p*-Chart

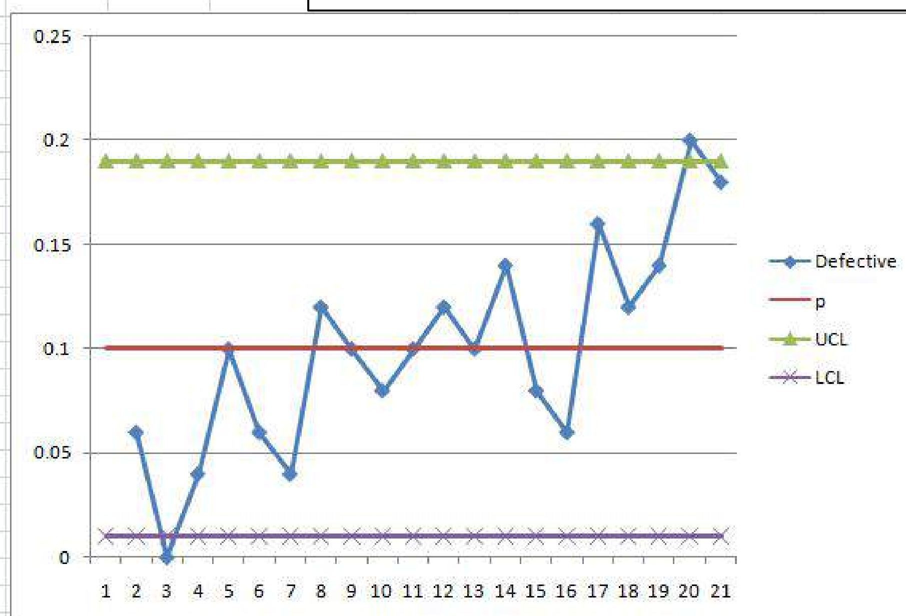
Sample	Proportion Defective	$\bar{p}$	UCL	LCL	Number of Defectives
0		0.10	0.19	0.01	
1	0.06	0.10	0.19	0.01	6
2	0.00	0.10	0.19	0.01	0
3	0.04	0.10	0.19	0.01	4
4	0.10	0.10	0.19	0.01	10
5	0.06	0.10	0.19	0.01	6
6	0.04	0.10	0.19	0.01	4
7	0.12	0.10	0.19	0.01	12
8	0.10	0.10	0.19	0.01	10
9	0.08	0.10	0.19	0.01	8
10	0.10	0.10	0.19	0.01	10
11	0.12	0.10	0.19	0.01	12
12	0.10	0.10	0.19	0.01	10
13	0.14	0.10	0.19	0.01	14
14	0.08	0.10	0.19	0.01	8
15	0.06	0.10	0.19	0.01	6
16	0.16	0.10	0.19	0.01	16
17	0.12	0.10	0.19	0.01	12
18	0.14	0.10	0.19	0.01	14
19	0.20	0.10	0.19	0.01	20
20	0.18	0.10	0.19	0.01	18
					200

Column values copied from I5 and I6

$\bar{p}$ =	0.10
UCL =	0.19
LCL =	0.01

I4 + 3*SQRT(I4*(1-I4)/100)

I4 - 3*SQRT(I4*(1-I4)/100)



c-Chart

$$UCL = \bar{c} + z\sigma_c$$

$$LCL = \bar{c} - z\sigma_c$$

$$\sigma_c = \sqrt{\bar{c}}$$

where

c = number of defects per sample

c-Chart

Number of defects in 15 sample rooms

SAMPLE	NUMBER OF DEFECTS
1	12
2	8
3	16
:	:
:	:
15	15
	190

$\bar{c} =$

$$UCL = c + z\sigma_c$$

$$LCL = c - z\sigma_c$$

c-Chart

Number of defects in 15 sample rooms

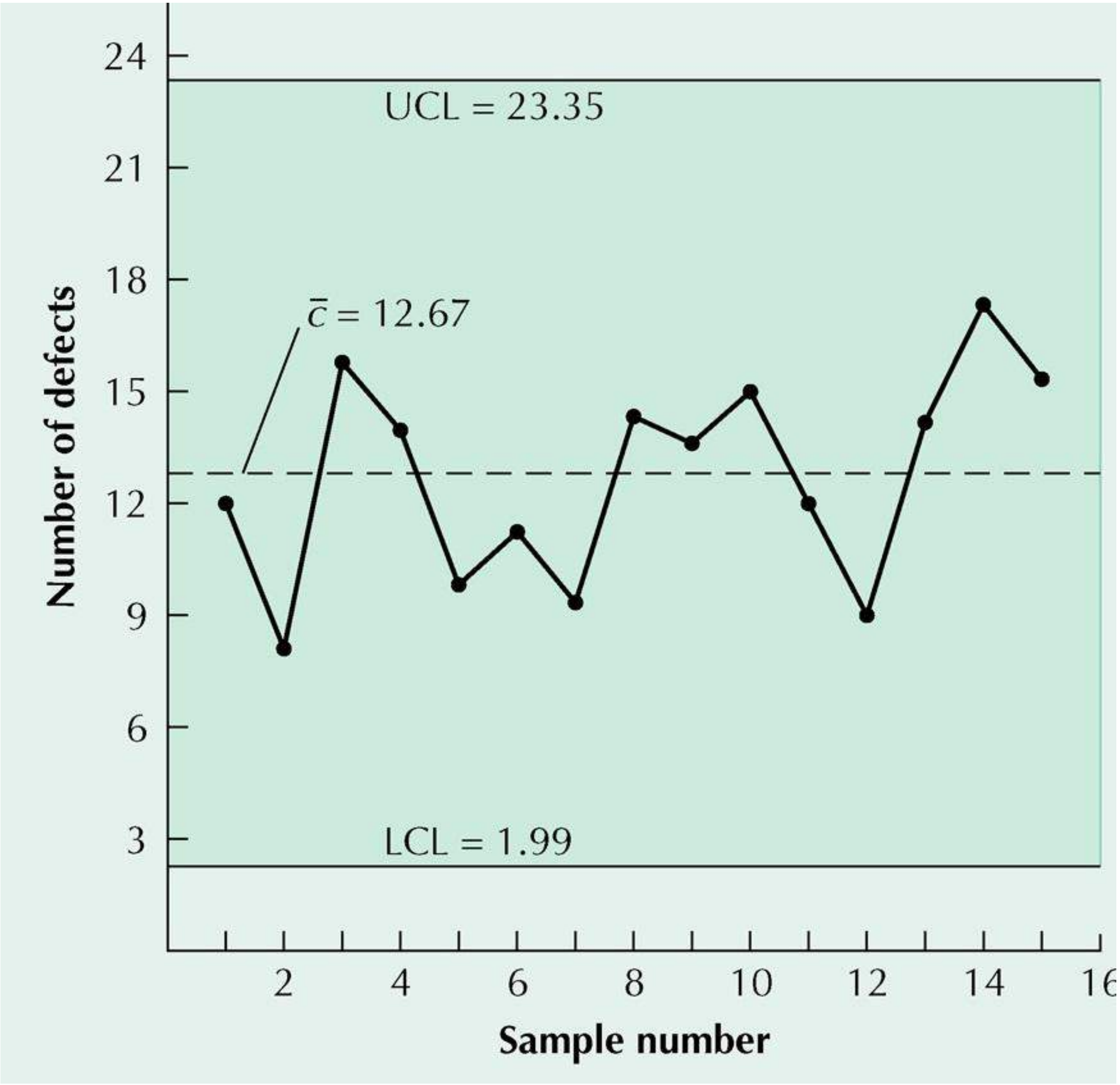
SAMPLE	NUMBER OF DEFECTS
1	12
2	8
3	16
:	:
:	:
15	15
	190

$$\bar{c} = \frac{190}{15} = 12.67$$

$$\begin{aligned} UCL &= \bar{c} + z\sigma_c \\ &= 12.67 + 3\sqrt{12.67} \\ &= 23.35 \end{aligned}$$

$$\begin{aligned} LCL &= \bar{c} - z\sigma_c \\ &= 12.67 - 3\sqrt{12.67} \\ &= 1.99 \end{aligned}$$

c-Chart



24
21
18
15
12
9
6
3
UCL = 23.35
$\bar{c}$ = 12.67
LCL = 1.99
Number of defects
2
4
6
8
10
12
14
16
Sample number

Control Charts for Variables

- Range chart (R-Chart)
  - Plot sample range (variability)
- Mean chart ($\bar{x}$ -Chart)
  - Plot sample averages

x-bar Chart: σ Known

$$UCL = \bar{\bar{x}} + z\,\sigma_{\bar{x}}$$
$$LCL = \bar{\bar{x}} - z\,\sigma_{\bar{x}}$$

Where

$$\bar{\bar{X}} = \frac{\bar{x}_1 + \bar{x}_2 + \dots + \bar{x}_k}{k}$$

σ = process standard deviation

σ_x = standard deviation of sample means $=\sigma/\sqrt{n}$

k = number of samples (subgroups)

n = sample size (number of observations)

x-bar Chart Example: σ Known

Sample k	Observations(Slip-Ring Diameter, cm) n: 1	2	3	4	5	$\bar{x}$
1	5.02	5.01	4.94	4.99	4.96	4.98
2	5.01	5.03	5.07	4.95	4.96	5.00
3	4.99	5.00	4.93	4.92	4.99	4.97
4	5.03	4.91	5.01	4.98	4.89	4.96
5	4.95	4.92	5.03	5.05	5.01	4.99
6	4.97	5.06	5.06	4.96	5.03	5.01
7	5.05	5.01	5.10	4.96	4.99	5.02
8	5.09	5.10	5.00	4.99	5.08	5.05
9	5.14	5.10	4.99	5.08	5.09	5.08
10	5.01	4.98	5.08	5.07	4.99	5.03
						50.09

We know σ = .08

x-bar Chart Example: σ Known

$$\bar{\bar{X}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_k}{k}$$

$$UCL = \bar{\bar{x}} + z\,\sigma_{\bar{x}}$$

$$LCL = \bar{\bar{x}} - z\,\sigma_{\bar{x}}$$

x-bar Chart Example: σ Known

$$\bar{\bar{x}} = \frac{50.09}{10} = 5.01$$

$$\begin{aligned} UCL &= \bar{\bar{x}} + z\,\sigma_{\bar{x}} \\ &= 5.01 + 3(.08/\sqrt{5}) \\ &= 5.12 \end{aligned}$$

$$\begin{aligned} LCL &= \bar{\bar{x}} - z\,\sigma_{\bar{x}} \\ &= 5.01 - 3(.08/\sqrt{5}) \\ &= 4.90 \end{aligned}$$

x-bar Chart Example: σ Unknown

$$UCL = \bar{\bar{x}} + A_2\bar{R} \qquad LCL = \bar{\bar{x}} - A_2\bar{R}$$

where

$\bar{\bar{x}}$ = average of the sample means

$\bar{R}$ = average range value

Control Chart Factors

Sample Size	Factor for X-chart	Factors for R-chart	
n	A2	D3	D4
2	1.880	0.000	3.267
3	1.023	0.000	2.575
4	0.729	0.000	2.282
5	0.577	0.000	2.114
6	0.483	0.000	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777
11	0.285	0.256	1.744
12	0.266	0.283	1.717
13	0.249	0.307	1.693
14	0.235	0.328	1.672
15	0.223	0.347	1.653
16	0.212	0.363	1.637
17	0.203	0.378	1.622
18	0.194	0.391	1.609
19	0.187	0.404	1.596
20	0.180	0.415	1.585
21	0.173	0.425	1.575
22	0.167	0.435	1.565
23	0.162	0.443	1.557
24	0.157	0.452	1.548
25	0.153	0.459	1.541

x-bar Chart Example: σ Unknown

	OBSERVATIONS (SLIP- RING DIAMETER, CM)						
SAMPLE *k*	*1*	*2*	*3*	*4*	*5*	$\bar{x}$	*R*
1	5.02	5.01	4.94	4.99	4.96	4.98	0.08
2	5.01	5.03	5.07	4.95	4.96	5.00	0.12
3	4.99	5.00	4.93	4.92	4.99	4.97	0.08
4	5.03	4.91	5.01	4.98	4.89	4.96	0.14
5	4.95	4.92	5.03	5.05	5.01	4.99	0.13
6	4.97	5.06	5.06	4.96	5.03	5.01	0.10
7	5.05	5.01	5.10	4.96	4.99	5.02	0.14
8	5.09	5.10	5.00	4.99	5.08	5.05	0.11
9	5.14	5.10	4.99	5.08	5.09	5.08	0.15
10	5.01	4.98	5.08	5.07	4.99	5.03	0.10
					Totals	50.09	1.15

Control Limits for the $\bar{x}$ Chart

$$\begin{aligned} \text{UCL} &= \bar{\bar{x}} + A_2\bar{R} \\ \text{Center line} &= \bar{\bar{x}} \\ \text{LCL} &= \bar{\bar{x}} - A_2\bar{R} \end{aligned} \tag{6.4}$$

The constant A_2 is tabulated for various sample sizes in Appendix Table VI.

Control Limits for the R Chart

$$\begin{aligned} \text{UCL} &= D_4\bar{R} \\ \text{Center line} &= \bar{R} \\ \text{LCL} &= D_3\bar{R} \end{aligned} \tag{6.5}$$

The constants D_3 and D_4 are tabulated for various values of n in Appendix Table VI.

$$\hat{\sigma} = \frac{\overline{R}}{d_2} \tag{6.6}$$

If we use $\overline{\overline{x}}$ as an estimator of μ and $\overline{R}/d_2$ as an estimator of σ, then the parameters of the $\overline{x}$ chart are

$$\begin{aligned} \text{UCL} &= \overline{\overline{x}} + \frac{3}{d_2\sqrt{n}}\overline{R} \\ \text{Center line} &= \overline{\overline{x}} \\ \text{LCL} &= \overline{\overline{x}} - \frac{3}{d_2\sqrt{n}}\overline{R} \end{aligned} \tag{6.7}$$

If we define

$$A_2 = \frac{3}{d_2\sqrt{n}} \tag{6.8}$$

then equation (6.7) reduces to equation (6.4).

x-bar Chart Example: σ Unknown

$$\bar{R} = \frac{\sum R}{k}$$

$$\bar{\bar{x}} = \frac{\sum \bar{x}}{k}$$

$$UCL = \bar{\bar{x}} + A_2\bar{R}$$

$$LCL = \bar{\bar{x}} - A_2\bar{R}$$

x-bar Chart Example: σ Unknown

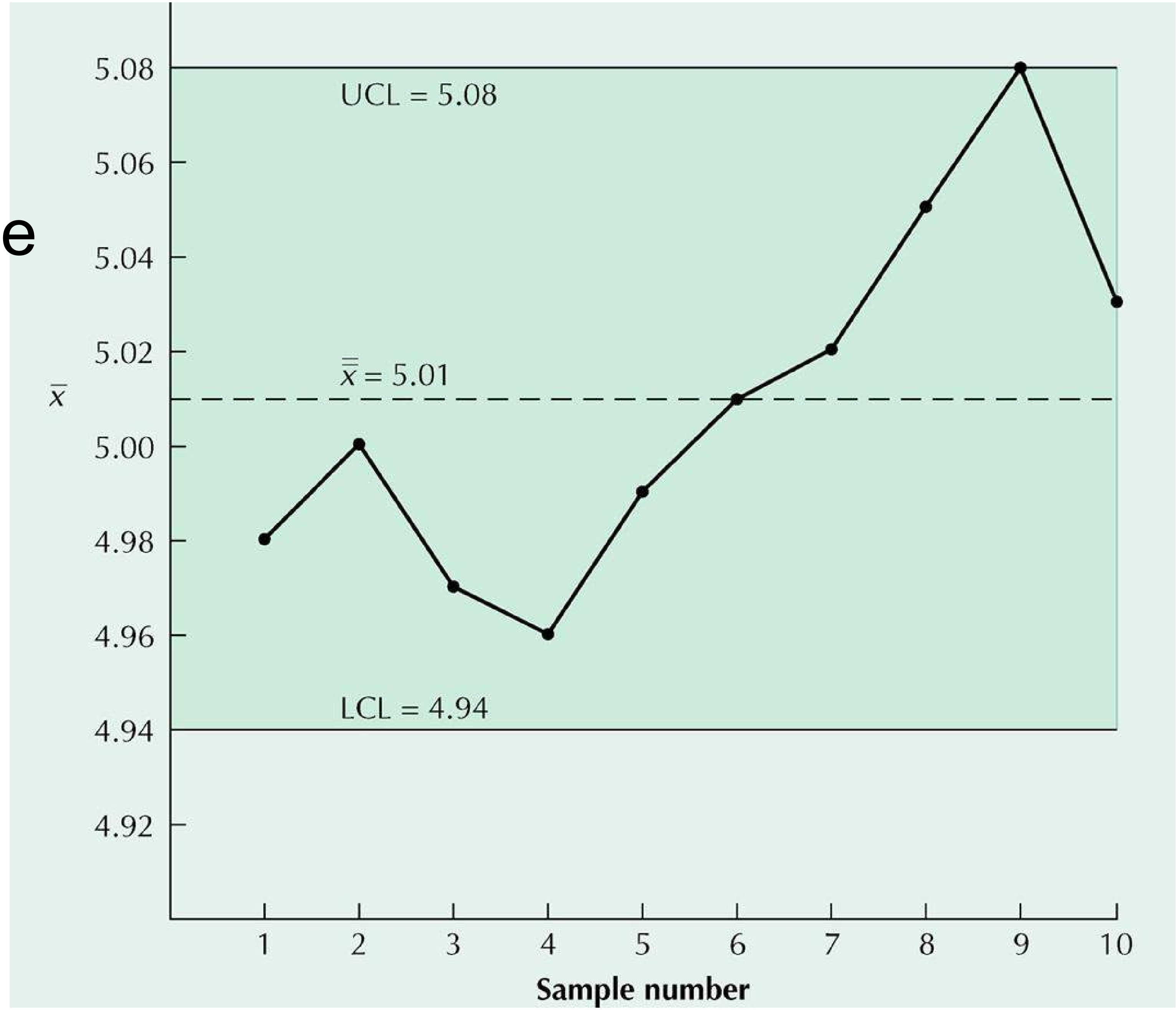
$$\overline{R} = \frac{\sum R}{k} = \frac{1.15}{10} = 0.115$$

$$\overline{\overline{x}} = \frac{\sum \overline{x}}{k} = \frac{50.09}{10} = 5.01 \text{ cm}$$

$$UCL = \overline{\overline{x}} + A_2\overline{R} = 5.01 + (0.58)(0.115) = 5.08$$

$$LCL = \overline{\overline{x}} - A_2\overline{R} = 5.01 - (0.58)(0.115) = 4.94$$

x- bar Chart Example



R- Chart

$$UCL = D_4\bar{R} \qquad LCL = D_3\bar{R}$$

$$\bar{R} = \frac{\sum R}{k}$$

Where

R = range of each sample

k = number of samples (sub groups)

Control Limits for the $\bar{x}$ Chart

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R}$$
$$\text{Center line} = \bar{\bar{x}} \qquad (6.4)$$
$$\text{LCL} = \bar{\bar{x}} - A_2\bar{R}$$

The constant A_2 is tabulated for various sample sizes in Appendix Table VI.

Control Limits for the *R* Chart

$$\text{UCL} = D_4\bar{R}$$
$$\text{Center line} = \bar{R} \qquad (6.5)$$
$$\text{LCL} = D_3\bar{R}$$

The constants D_3 and D_4 are tabulated for various values of n in Appendix Table VI.

Now consider the R chart. The center line will be $\overline{R}$. To determine the control limits, we need an estimate of σ_R. Assuming that the quality characteristic is normally distributed, $\hat{\sigma}_R$ can be found from the distribution of the relative range $W = R/\sigma$. The standard deviation of W, say d_3, is a known function of n. Thus, since

$$R = W\sigma$$

the standard deviation of R is

$$\sigma_R = d_3\sigma$$

Since σ is unknown, we may estimate σ_R by

$$\hat{\sigma}_R = d_3\frac{\overline{R}}{d_2} \tag{6.9}$$

Consequently, the parameters of the R chart with the usual three-sigma control limits are

$$\begin{aligned} \text{UCL} &= \overline{R} + 3\hat{\sigma}_R = \overline{R} + 3d_3\frac{\overline{R}}{d_2} \\ \text{Center line} &= \overline{R} \\ \text{LCL} &= \overline{R} - 3\hat{\sigma}_R = \overline{R} - 3d_3\frac{\overline{R}}{d_2} \end{aligned} \tag{6.10}$$

If we let

$$D_3 = 1 - 3\frac{d_3}{d_2} \quad \text{and} \quad D_4 = 1 + 3\frac{d_3}{d_2}$$

equation (6.10) reduces to equation (6.5).

R-Chart Example

	OBSERVATIONS (SLIP- RING DIAMETER, CM)						
SAMPLE *k*	*1*	*2*	*3*	*4*	*5*	$\bar{x}$	*R*
1	5.02	5.01	4.94	4.99	4.96	4.98	0.08
2	5.01	5.03	5.07	4.95	4.96	5.00	0.12
3	4.99	5.00	4.93	4.92	4.99	4.97	0.08
4	5.03	4.91	5.01	4.98	4.89	4.96	0.14
5	4.95	4.92	5.03	5.05	5.01	4.99	0.13
6	4.97	5.06	5.06	4.96	5.03	5.01	0.10
7	5.05	5.01	5.10	4.96	4.99	5.02	0.14
8	5.09	5.10	5.00	4.99	5.08	5.05	0.11
9	5.14	5.10	4.99	5.08	5.09	5.08	0.15
10	5.01	4.98	5.08	5.07	4.99	5.03	0.10
					Totals	50.09	1.15

R-Chart Example

$UCL = D_4\bar{R} =$

$LCL = D_3\bar{R} =$

Retrieve chart factors D_3 and D_4

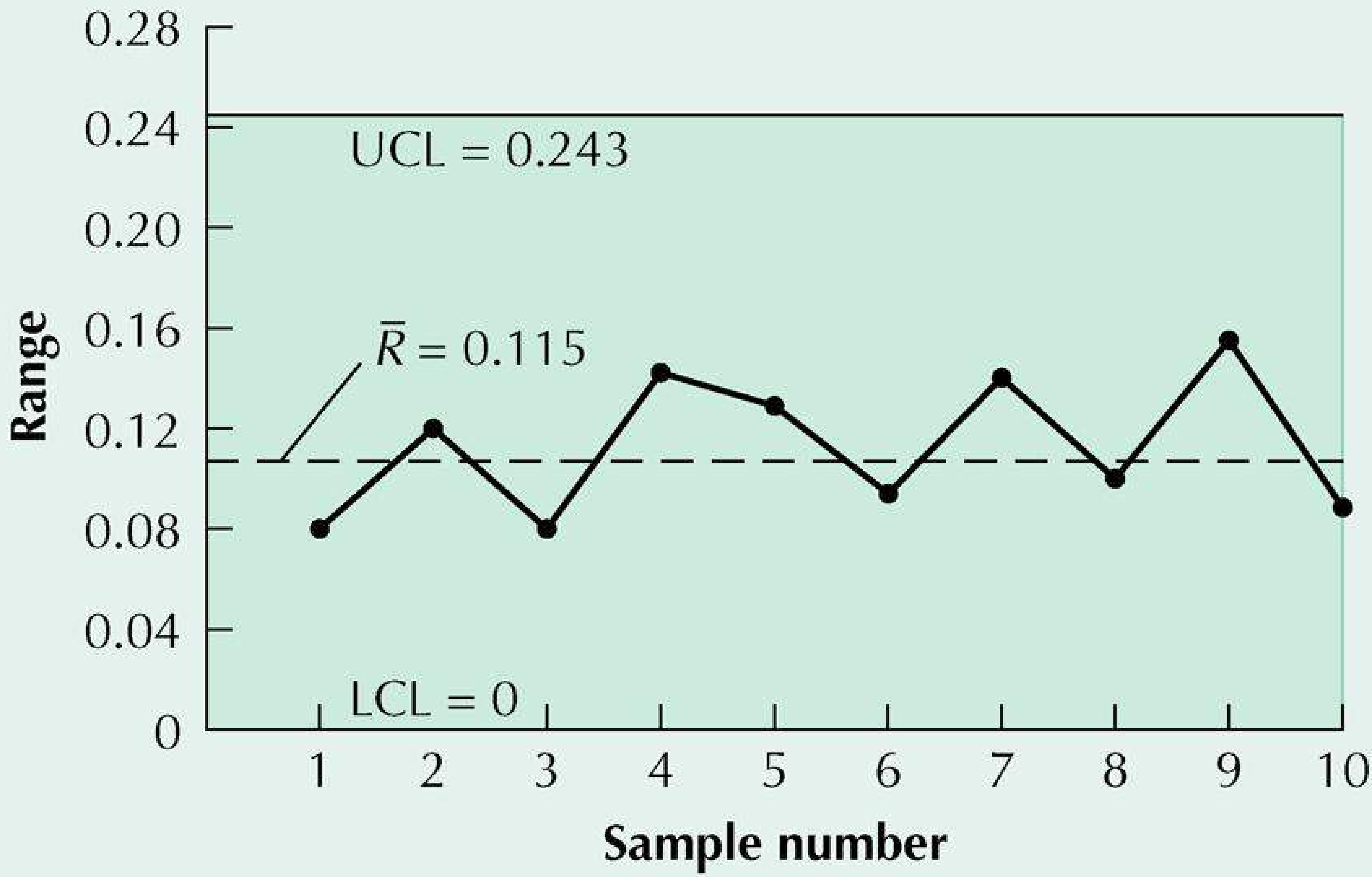
R-Chart Example

$$UCL = D_4\bar{R} = 2.11(0.115) = 0.243$$

$$LCL = D_3\bar{R} = 0(0.115) = 0$$

Retrieve chart factors D_3 and D_4

R-Chart Example



X-bar and R charts – Excel & OM Tools

F5 =F6+J5*G6

Xbar and R Charts OM Student - Examples 3.4 and 3.5

Input:

No. of samples	10
Sample size	5

Output:

	X-Bar	Range
UCL	5.08	0.24
Mean	5.01	0.12
LCL	4.94	0.00

Table Values

N	5
A2	0.577
D3	0.00
D4	2.115

Input the observations for each sample in the green shaded cells.

	Observations					Calculations		Xbar Chart		R-chart	
Sample	1	2	3	4	5	Sample Mean	Range	UCL	LCL	UCL	LCL
1	5.02	5.01	4.94	4.99	4.96	4.98	0.08	5.08	4.94	0.243	0
2	5.01	5.03	5.07	4.95	4.96	5.00	0.12	5.08	4.94	0.243	0
3	4.99	5.00	4.93	4.92	4.99	4.97	0.08	5.08	4.94	0.243	0
4	5.03	4.91	5.01	4.98	4.89	4.96	0.14	5.08	4.94	0.243	0
5	4.95	4.92	5.03	5.05	5.01	4.99	0.13	5.08	4.94	0.243	0
6	4.97	5.06	5.06	4.96	5.03	5.02	0.10	5.08	4.94	0.243	0
7	5.05	5.01	5.10	4.96	4.99	5.02	0.14	5.08	4.94	0.243	0
8	5.09	5.10	5.00	4.99	5.08	5.05	0.11	5.08	4.94	0.243	0
9	5.14	5.10	4.99	5.08	5.09	5.08	0.15	5.08	4.94	0.243	0
10	5.01	4.98	5.08	5.07	4.99	5.03	0.10	5.08	4.94	0.243	0
					Mean	5.01	0.115				

Xbar chart formulas

$$LCL = \bar{\bar{x}} - A_2 \bar{R}$$

$$UCL = \bar{\bar{x}} + A_2 \bar{R}$$

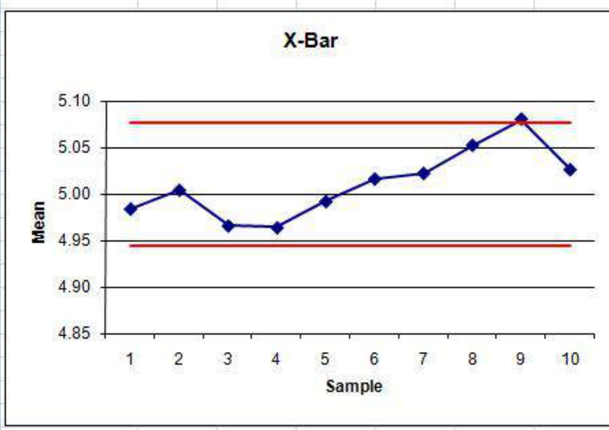
R-chart formulas

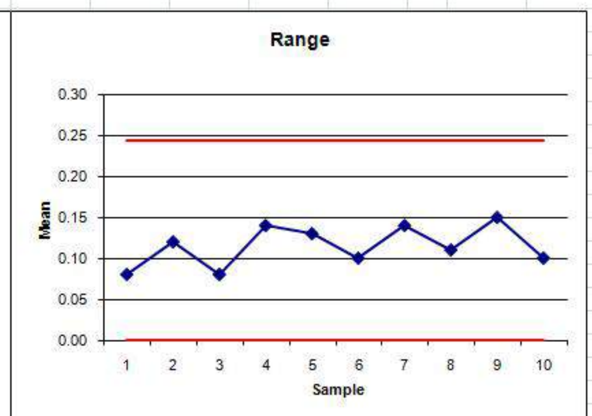
$$LCL = D_3 \bar{R}$$

$$UCL = D_4 \bar{R}$$

Control Chart Factors for Xbar and R Charts

Sample size, n	Mean Factor, A2	Upper Range, D4	Lower Range, D3
2	1.88	3.268	0
3	1.023	2.574	0
4	0.729	2.282	0
5	0.577	2.115	0
6	0.483	2.004	0
7	0.419	1.924	0.076
8	0.373	1.864	0.136
9	0.337	1.816	0.184
10	0.308	1.777	0.223
11	0.285	1.744	0.256
12	0.266	1.716	0.284
13	0.249	1.692	0.308
14	0.235	1.671	0.329
15	0.223	1.652	0.348
16	0.212	1.636	0.364
17	0.203	1.621	0.379
18	0.194	1.608	0.392
19	0.187	1.596	0.404
20	0.180	1.586	0.414
21	0.173	1.575	0.425
22	0.167	1.566	0.434
23	0.162	1.557	0.443
24	0.157	1.548	0.452
25	0.153	1.541	0.459





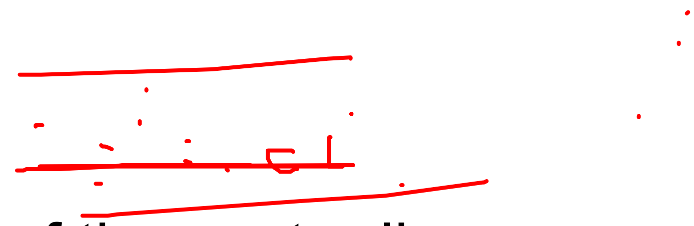
Using x- bar and R-Charts Together

- Process average and process variability must be in control
- Samples can have very narrow ranges, but sample averages might be beyond control limits
- Or, sample averages may be in control, but ranges might be out of control
- An R-chart might show a distinct downward trend, suggesting some nonrandom cause is reducing variation

Control Chart Patterns

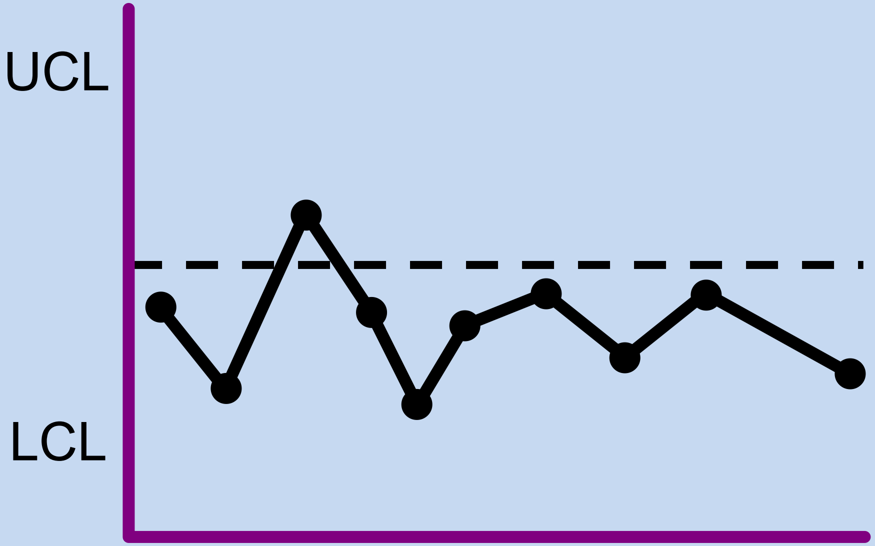
- Run
  - sequence of sample values that display same characteristic
- Pattern test
  - determines if observations within limits of a control chart display a nonrandom pattern

Control Chart Patterns

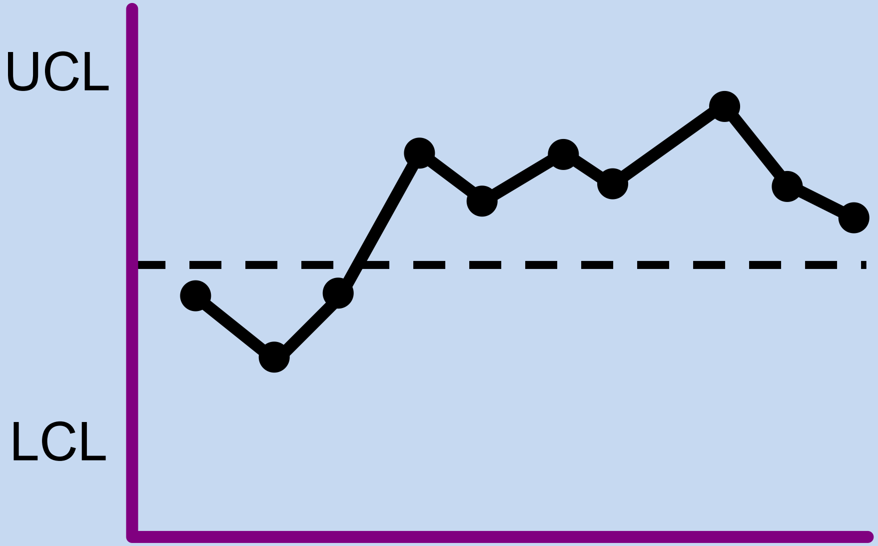


- To identify a pattern look for:
  - 8 consecutive points on one side of the center line
  - 8 consecutive points up or down
  - 14 points alternating up or down
  - 2 out of 3 consecutive points in zone A (on one side of center line)
  - 4 out of 5 consecutive points in zone A or B (on one side of center line)

Control Chart Patterns

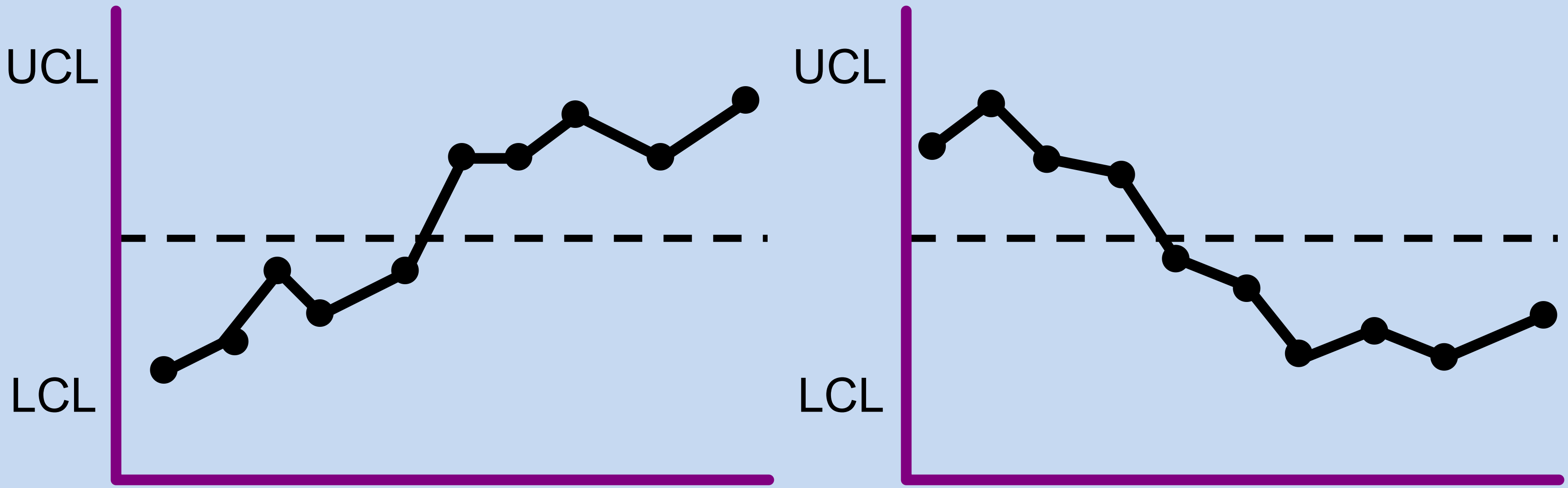


Sample observations consistently below the center line



Sample observations consistently above the center line

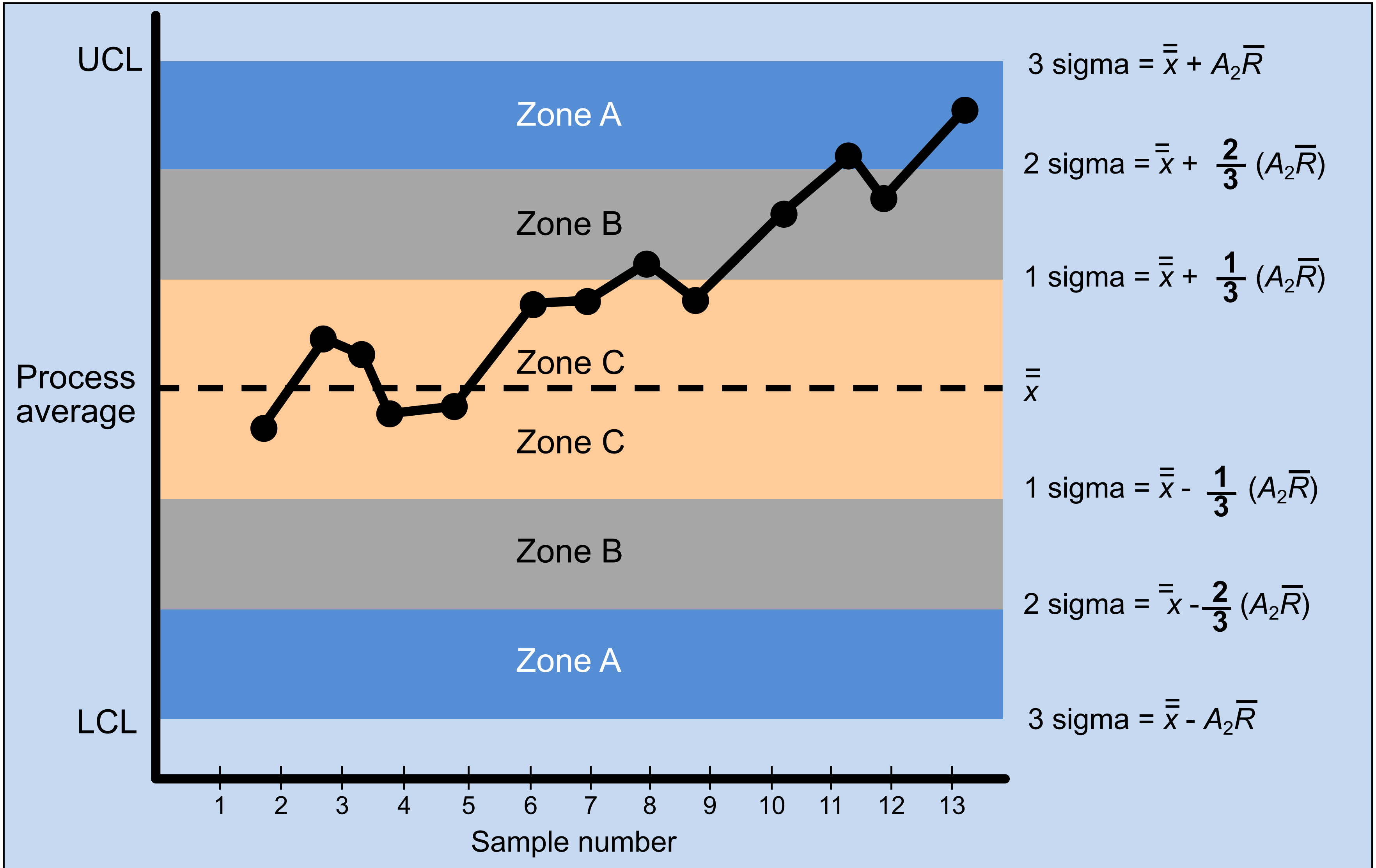
Control Chart Patterns



Sample observations consistently increasing

Sample observations consistently decreasing

Zones for Pattern Tests



Performing a Pattern Test

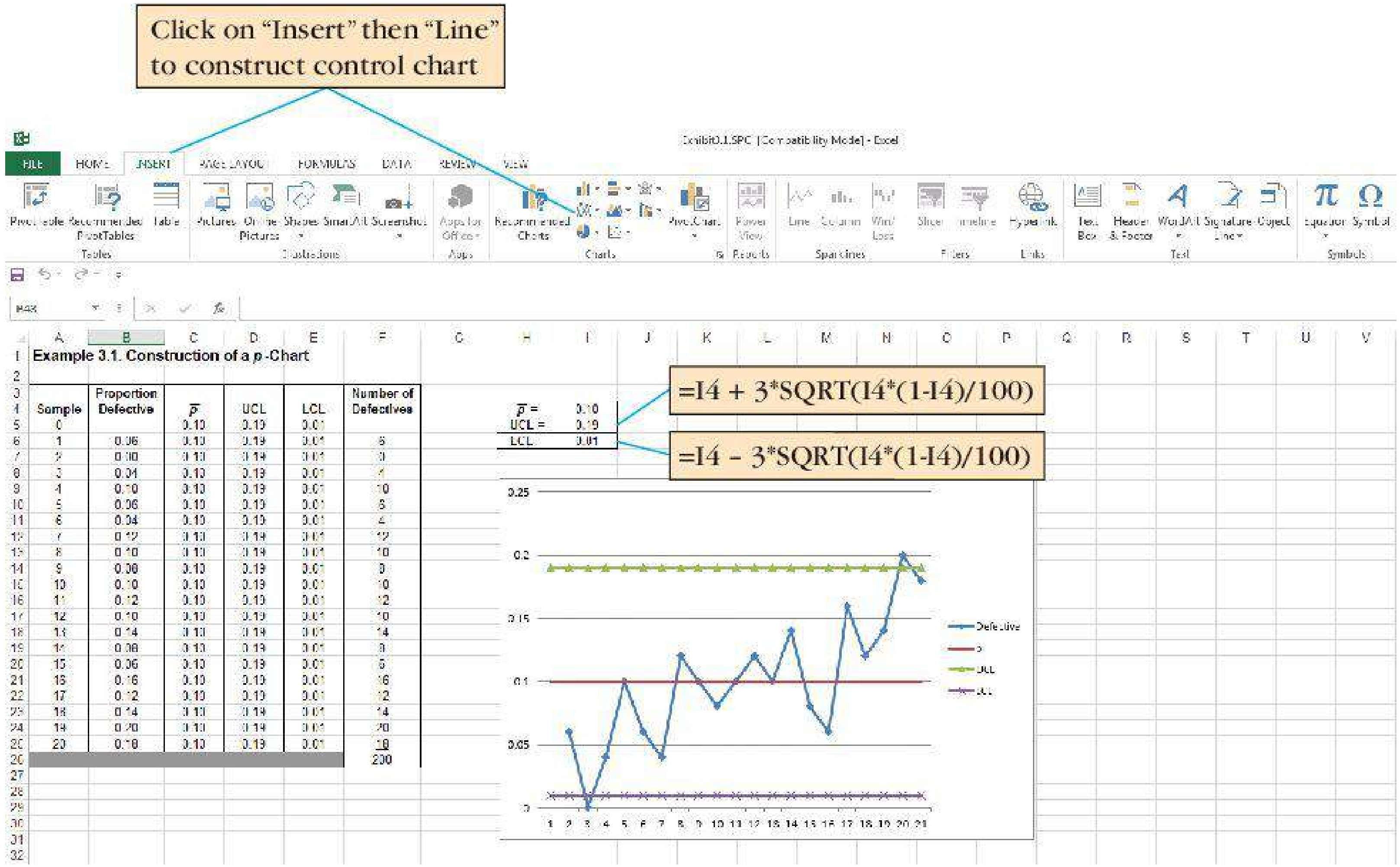
SAMPLE	$\bar{x}$	ABOVE/BELOW	UP/DOWN	ZONE
1	4.98	B	—	B
2	5.00	B	U	C
3	4.95	B	D	A
4	4.96	B	D	A
5	4.99	B	U	C
6	5.01	—	U	C
7	5.02	A	U	C
8	5.05	A	U	B
9	5.08	A	U	A
10	5.03	A	D	B

Sample Size Determination

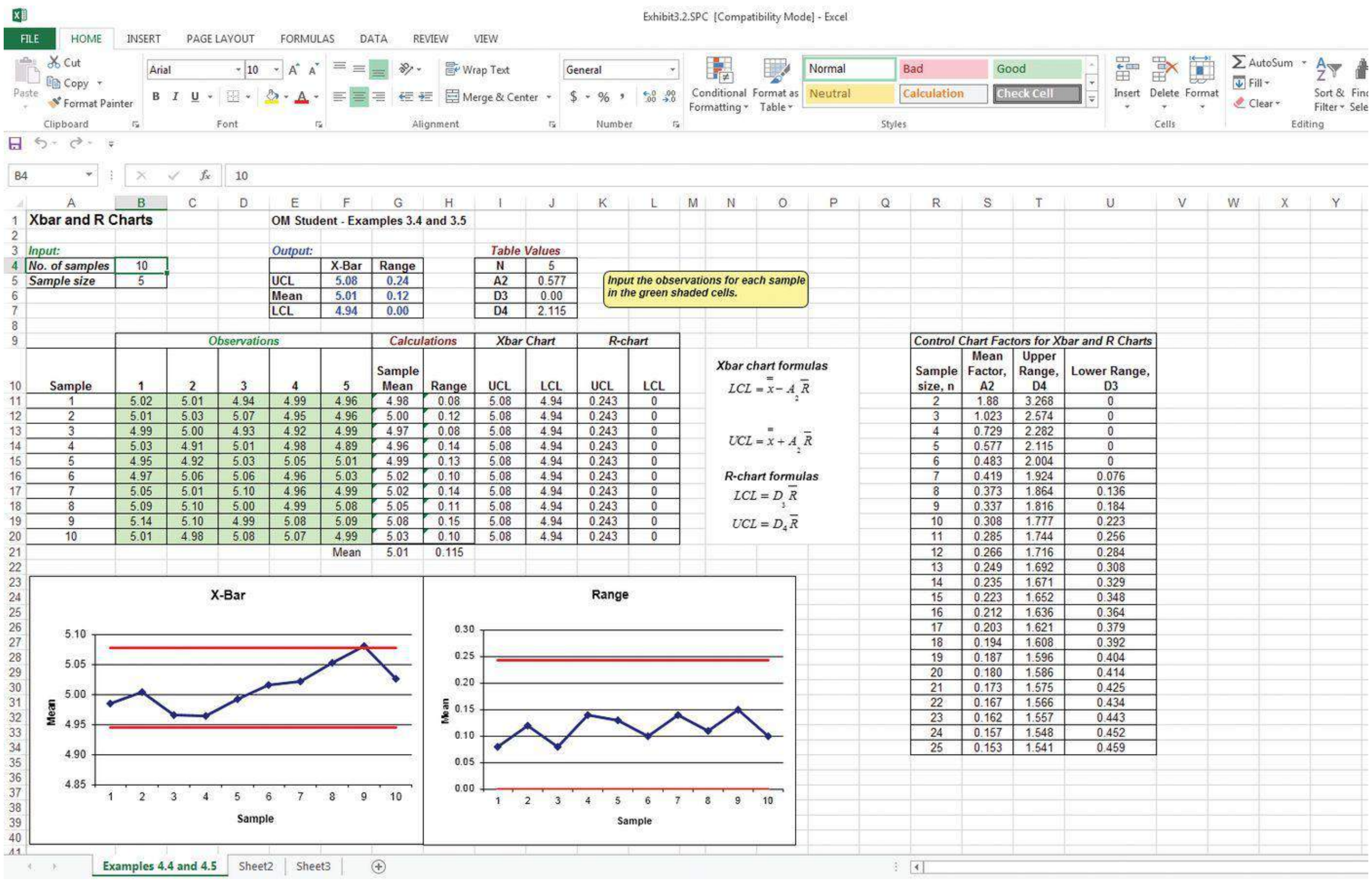
- Attribute charts require larger sample sizes
  - 50 to 100 parts in a sample

- Variable charts require smaller samples
  - 2 to 10 parts in a sample

SPC with Excel



SPC with OM Tools



Input:

No. of samples	10
Sample size	5

Output:

	X-Bar	Range
UCL	5.08	0.24
Mean	5.01	0.12
LCL	4.94	0.00

Table Values

N	5
A2	0.577
D3	0.00
D4	2.115

	Observations					Calculations		Xbar Chart		R-chart	
Sample	1	2	3	4	5	Sample Mean	Range	UCL	LCL	UCL	LCL
1	5.02	5.01	4.94	4.99	4.96	4.98	0.08	5.08	4.94	0.243	0
2	5.01	5.03	5.07	4.95	4.96	5.00	0.12	5.08	4.94	0.243	0
3	4.99	5.00	4.93	4.92	4.99	4.97	0.08	5.08	4.94	0.243	0
4	5.03	4.91	5.01	4.98	4.89	4.96	0.14	5.08	4.94	0.243	0
5	4.95	4.92	5.03	5.05	5.01	4.99	0.13	5.08	4.94	0.243	0
6	4.97	5.06	5.06	4.96	5.03	5.02	0.10	5.08	4.94	0.243	0
7	5.05	5.01	5.10	4.96	4.99	5.02	0.14	5.08	4.94	0.243	0
8	5.09	5.10	5.00	4.99	5.08	5.05	0.11	5.08	4.94	0.243	0
9	5.14	5.10	4.99	5.08	5.09	5.08	0.15	5.08	4.94	0.243	0
10	5.01	4.98	5.08	5.07	4.99	5.03	0.10	5.08	4.94	0.243	0
					Mean	5.01	0.115				

Control Chart Factors for Xbar and R Charts

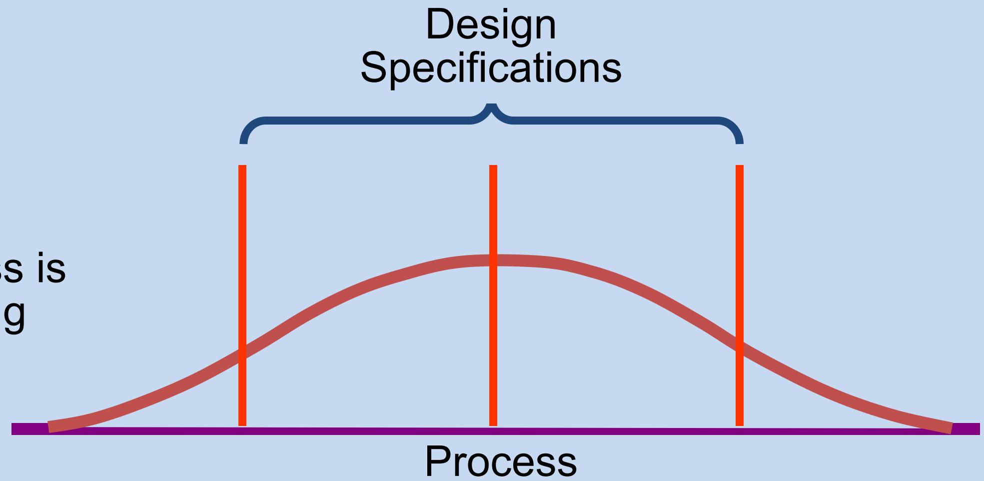
Sample size, n	Mean Factor, A2	Upper Range, D4	Lower Range, D3
2	1.88	3.268	0
3	1.023	2.574	0
4	0.729	2.282	0
5	0.577	2.115	0
6	0.483	2.004	0
7	0.419	1.924	0.076
8	0.373	1.864	0.136
9	0.337	1.816	0.184
10	0.308	1.777	0.223
11	0.285	1.744	0.256
12	0.266	1.716	0.284
13	0.249	1.692	0.308
14	0.235	1.671	0.329
15	0.223	1.652	0.348
16	0.212	1.636	0.364
17	0.203	1.621	0.379
18	0.194	1.608	0.392
19	0.187	1.596	0.404
20	0.180	1.586	0.414
21	0.173	1.575	0.425
22	0.167	1.566	0.434
23	0.162	1.557	0.443
24	0.157	1.548	0.452
25	0.153	1.541	0.459

Process Capability

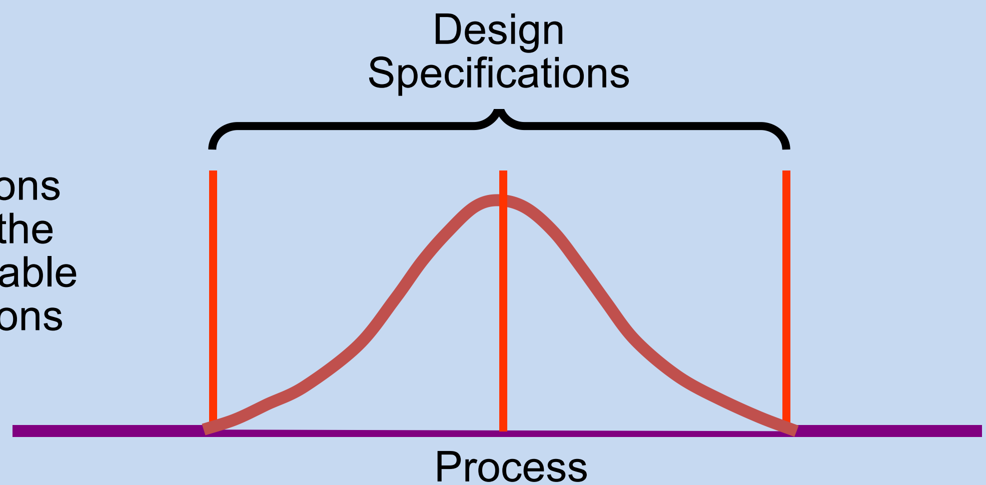
- Compare natural variability to design variability
- Natural variability
  - What we measure with control charts
  - Process mean = 8.80 oz, Std dev. = 0.12 oz
- Tolerances
  - Design specifications reflecting product requirements
  - Net weight = 9.0 oz $\pm$ 0.5 oz
  - Tolerances are $\pm$ 0.5 oz

Process Capability

(a) Natural variation exceeds design specifications; process is not capable of meeting specifications all the time.

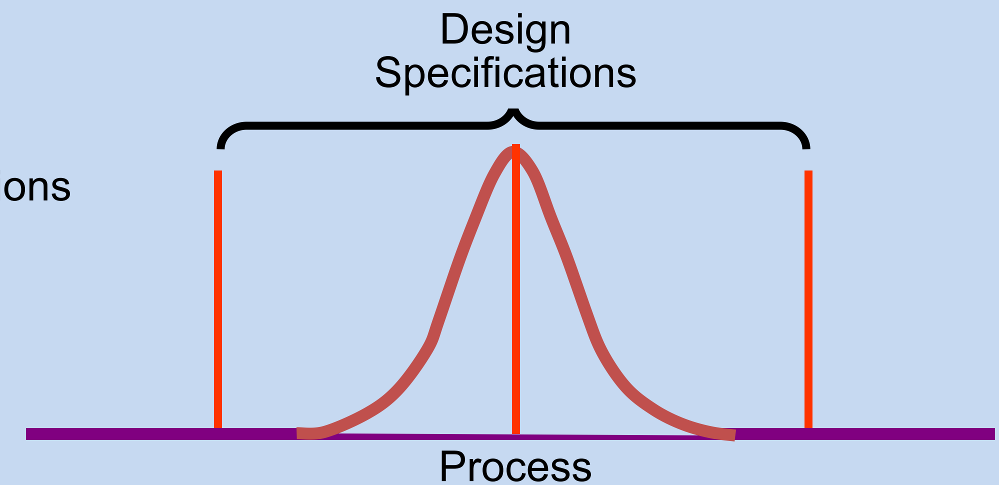


(b) Design specifications and natural variation the same; process is capable of meeting specifications most of the time.

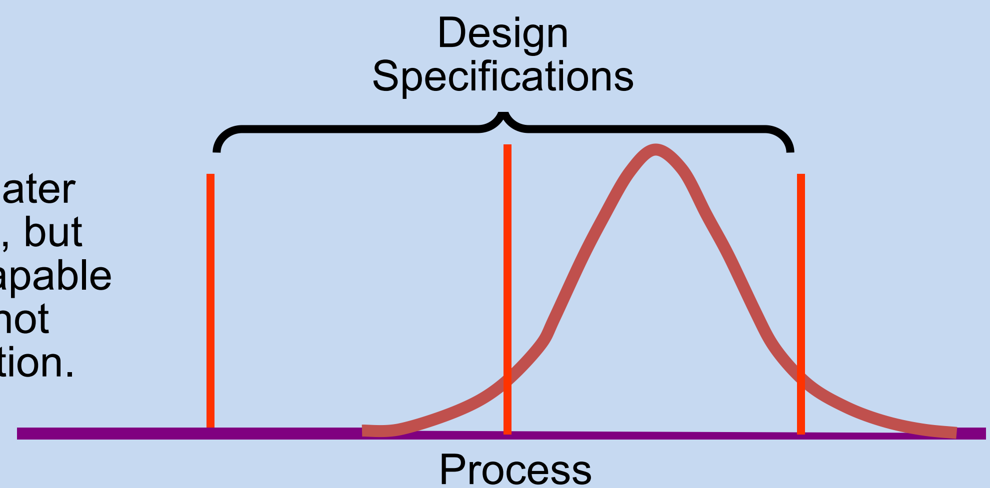


Process Capability

(c) Design specifications greater than natural variation; process is capable of always conforming to specifications.



(d) Specifications greater than natural variation, but process off center; capable but some output will not meet upper specification.



Process Capability Ratio

$$C_p = \frac{\text{tolerance range}}{\text{process range}}$$

$$= \frac{\text{upper spec limit - lower spec limit}}{6\sigma}$$

Computing C_p

Net weight specification = 9.0 oz $\pm$ 0.5 oz
Process mean = 8.80 oz
Process standard deviation = 0.12 oz

$$C_p = \frac{\text{upper specification limit - lower specification limit}}{6\sigma}$$

Computing C_p

Net weight specification = 9.0 oz $\pm$ 0.5 oz
Process mean = 8.80 oz
Process standard deviation = 0.12 oz

$$C_p = \frac{\text{upper specification limit} - \text{lower specification limit}}{6\sigma}$$

$$= \frac{9.5 - 8.5}{6(0.12)} = 1.39$$

Process Capability Index

$$C_{pk} = \text{minimum}\left[\frac{\bar{\bar{x}} - \text{lower specification limit}}{3\sigma},\ \frac{\text{upper specification limit} - \bar{\bar{x}}}{3\sigma}\right]$$

Computing C_{pk}

Net weight specification = 9.0 oz $\pm$ 0.5 oz
Process mean = 8.80 oz
Process standard deviation = 0.12 oz

$$C_{pk} = \text{minimum}\left[\frac{\bar{\bar{x}} - \text{lower specification limit}}{3\sigma}, \frac{\text{upper specification limit} - \bar{\bar{x}}}{3\sigma}\right]$$

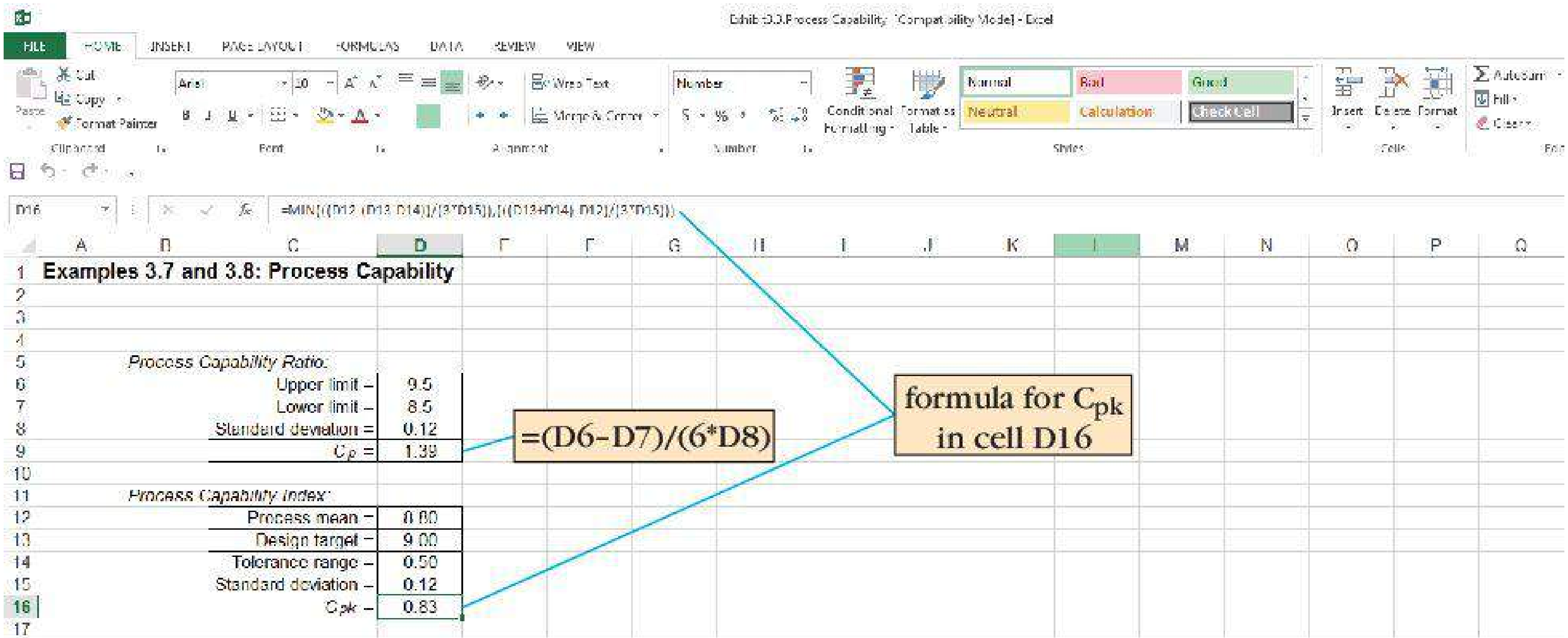
Computing C_{pk}

Net weight specification = 9.0 oz $\pm$ 0.5 oz
Process mean = 8.80 oz
Process standard deviation = 0.12 oz

$$C_{pk} = \text{minimum}\left[\frac{\bar{\bar{x}} - \text{lower specification limit}}{3\sigma}, \frac{\text{upper specification limit} - \bar{\bar{x}}}{3\sigma}\right]$$

$$= \text{minimum}\left[\frac{8.80 - 8.50}{3(0.12)}, \frac{9.50 - 8.80}{3(0.12)}\right] = 0.83$$

Process Capability With Excel



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

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

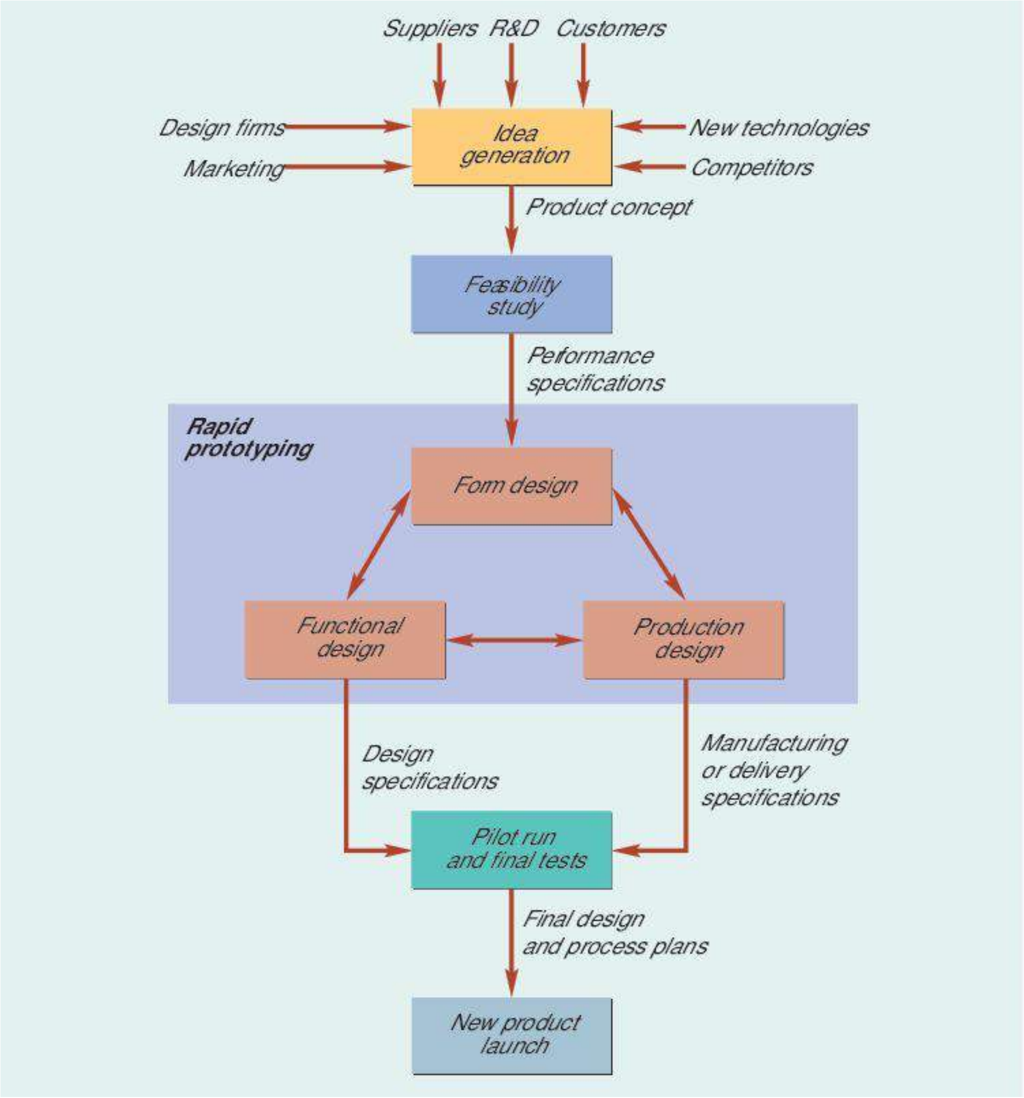
- The driving forces for product and service design or redesign are market opportunities or threats:
  - Economic
  - Social and Demographic
  - Political, Liability, or Legal
  - Competitive
  - Cost or Availability
  - Technological

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

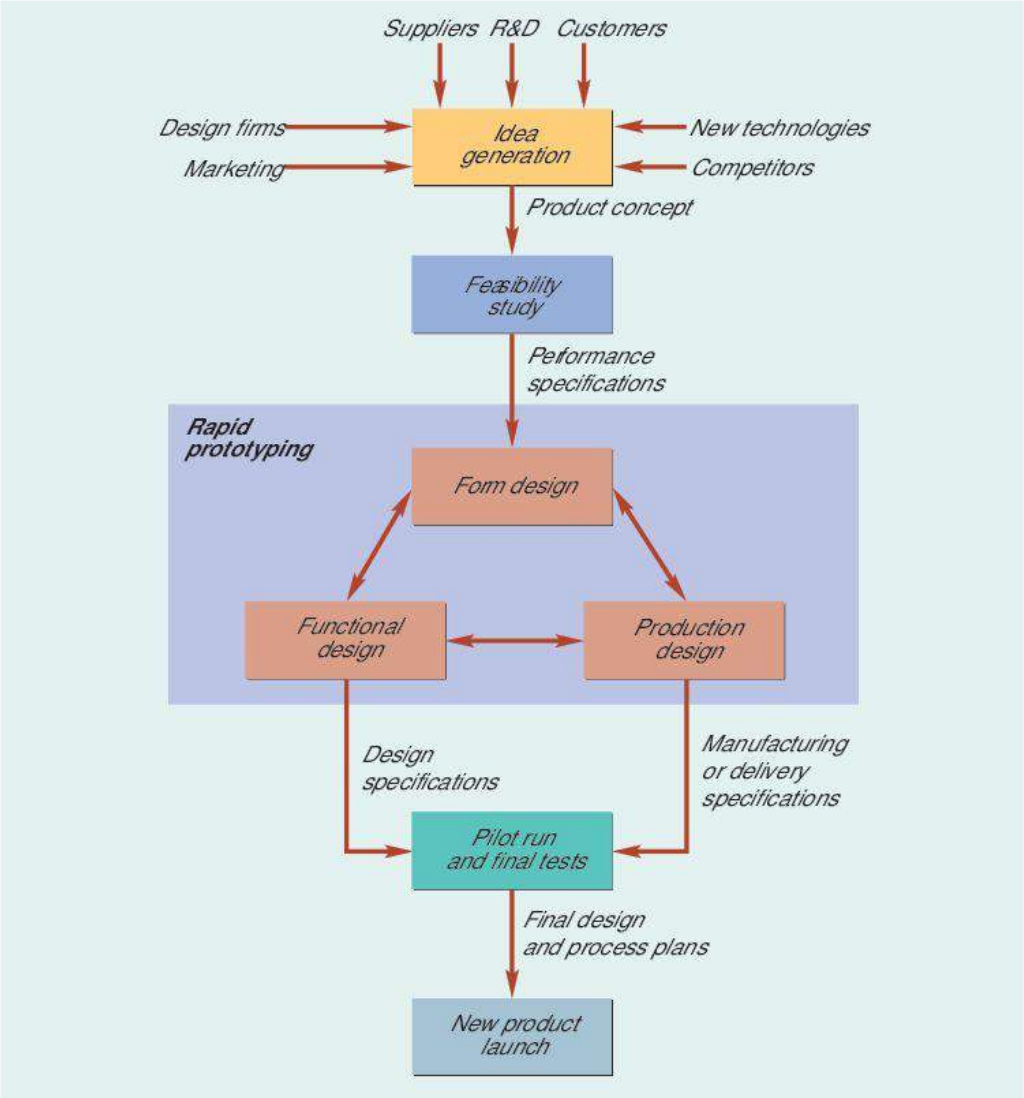
- Company's own R&D department
- Customer complaints or suggestions
- Marketing research
- Suppliers
- Salespersons in the field
- Factory workers
- New technological developments
- Competitors

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

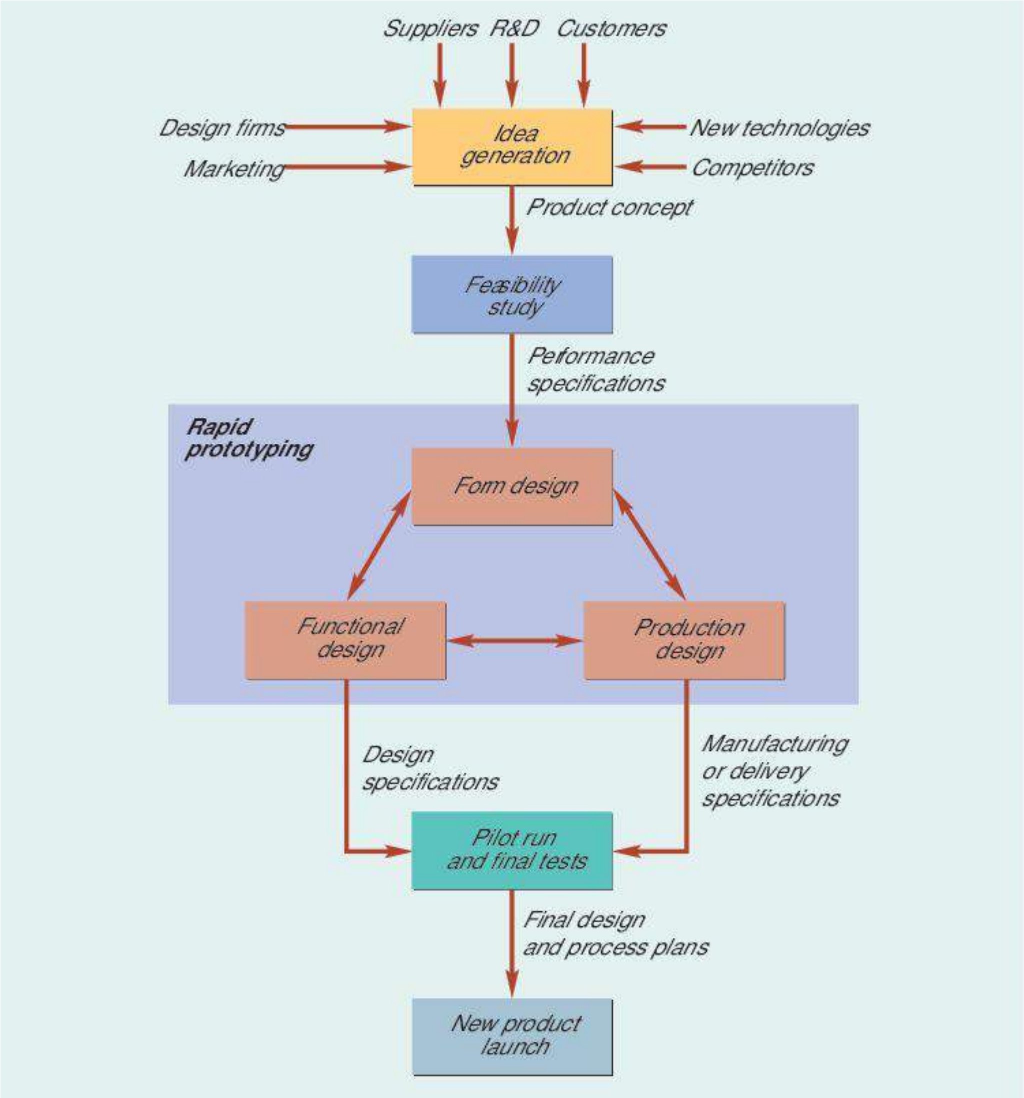
Design Process



Feasibility Study

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

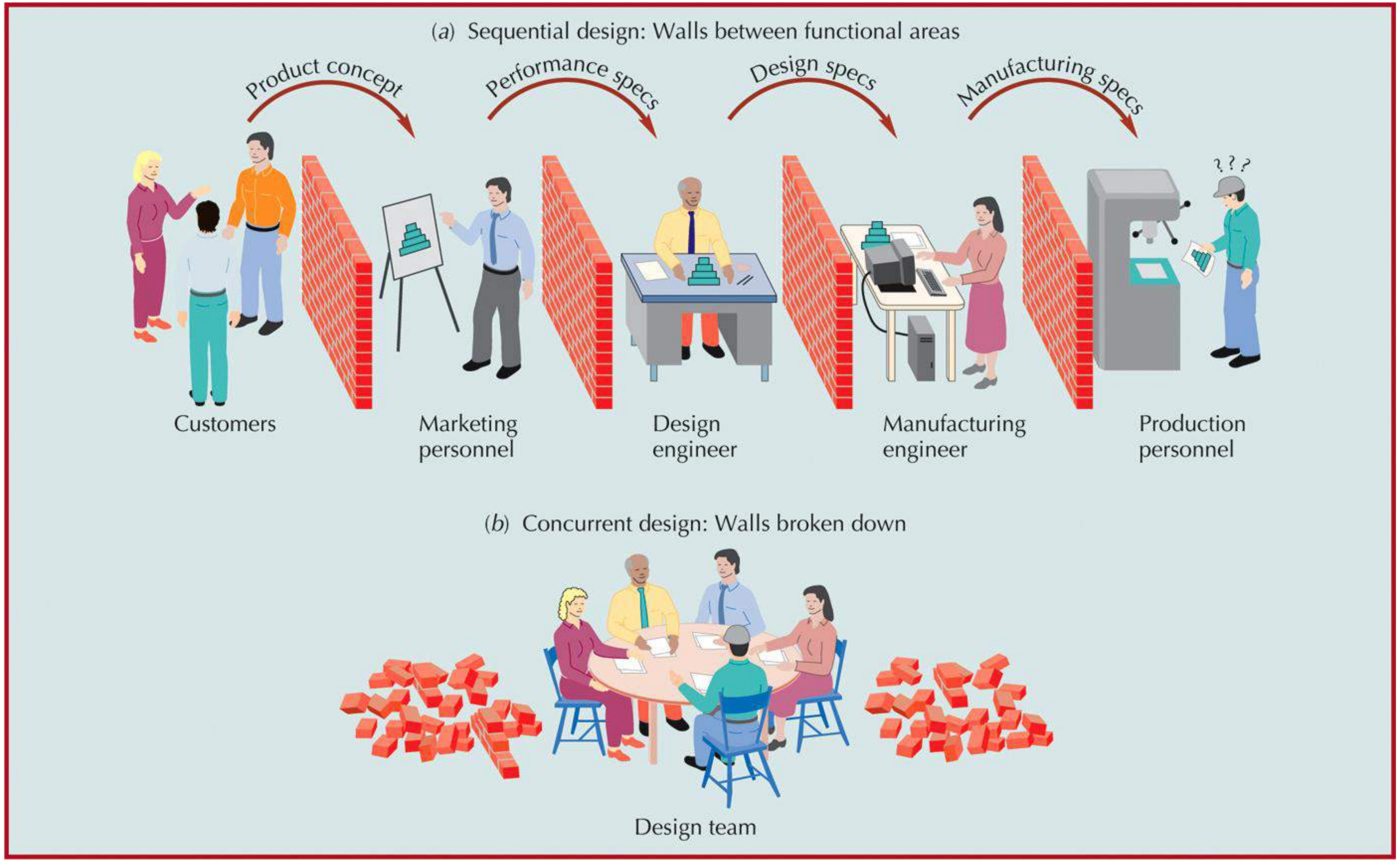
Design Process



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

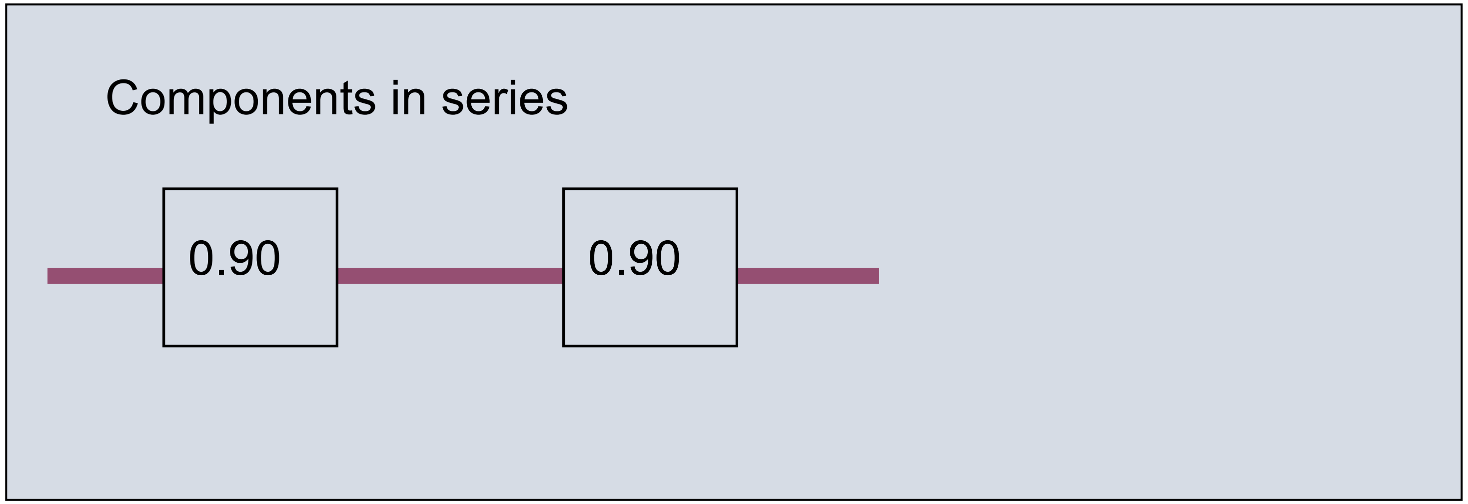
Reliability

- **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

Computing Reliability

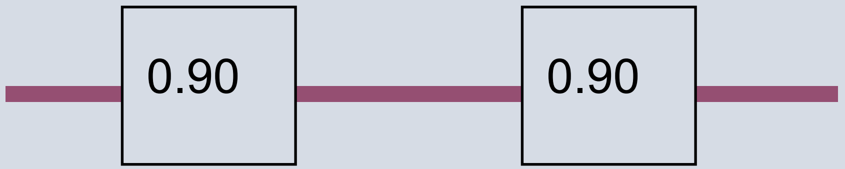
Rule 1

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

Components in series

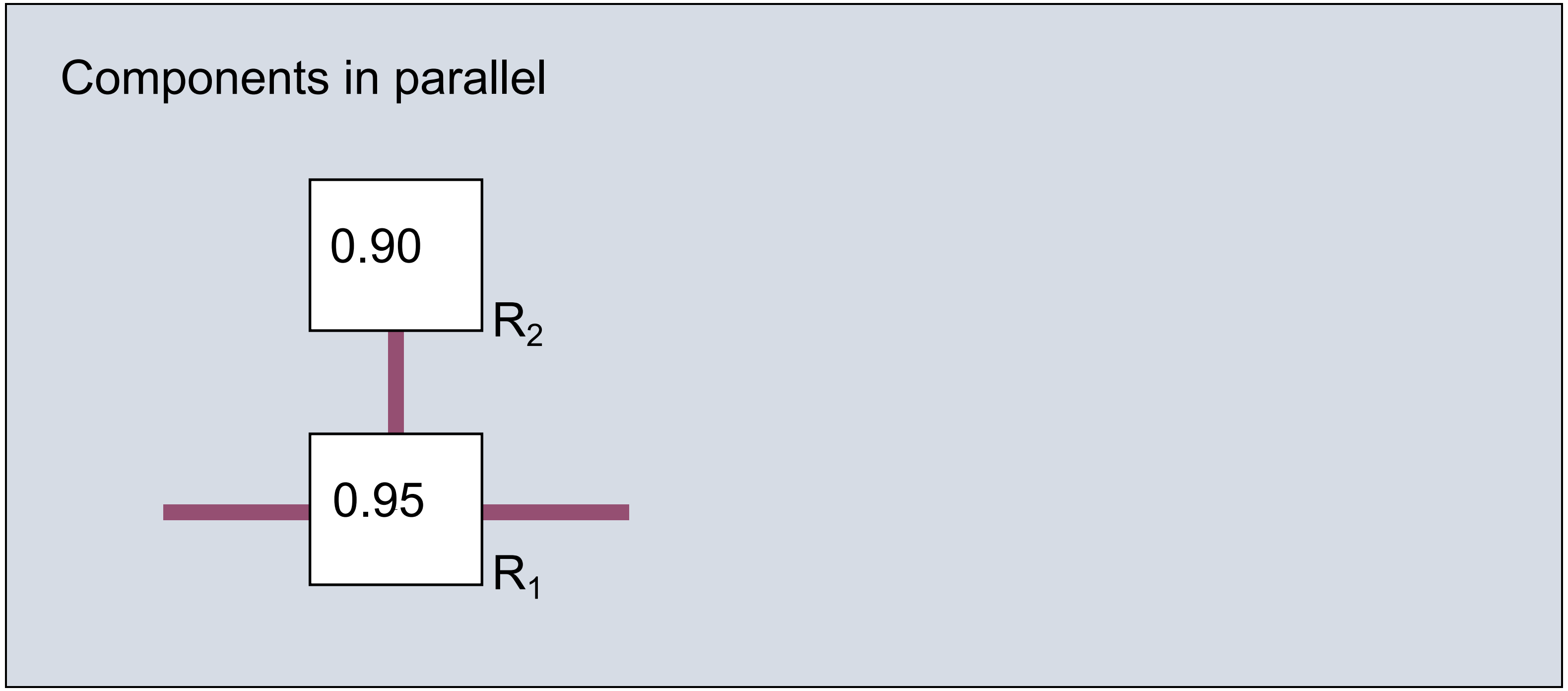


0.90 x 0.90 = 0.81

Computing Reliability

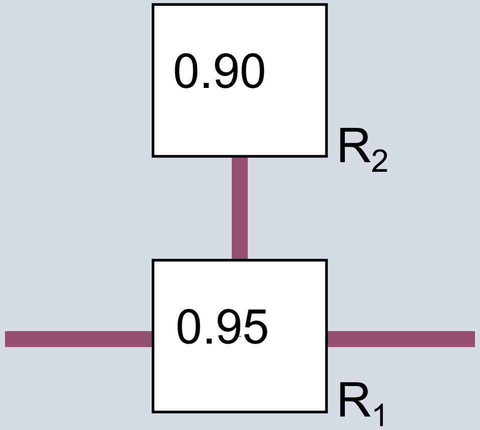
Rule 2

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



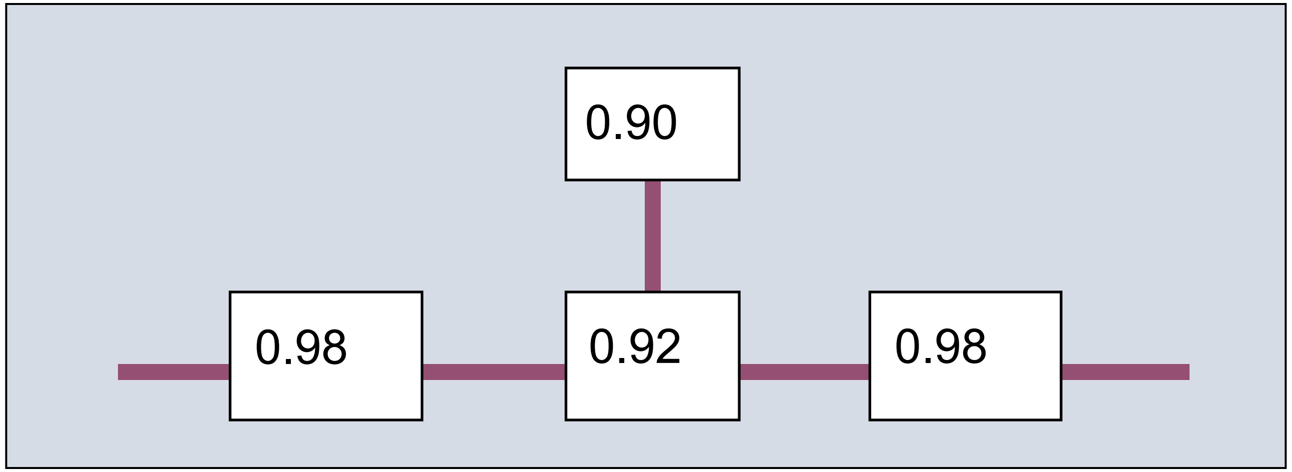
Computing Reliability

Components in parallel

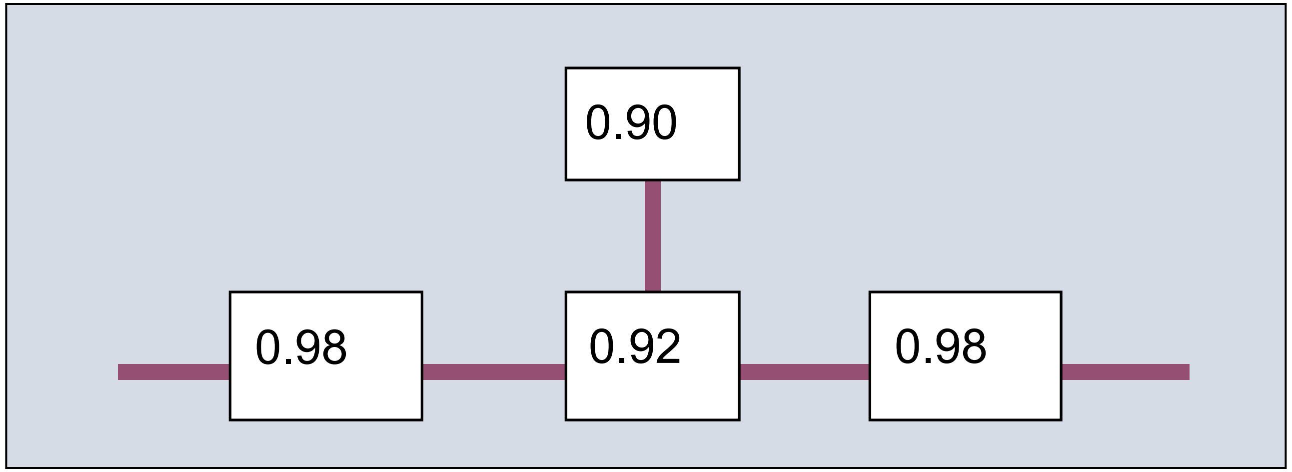


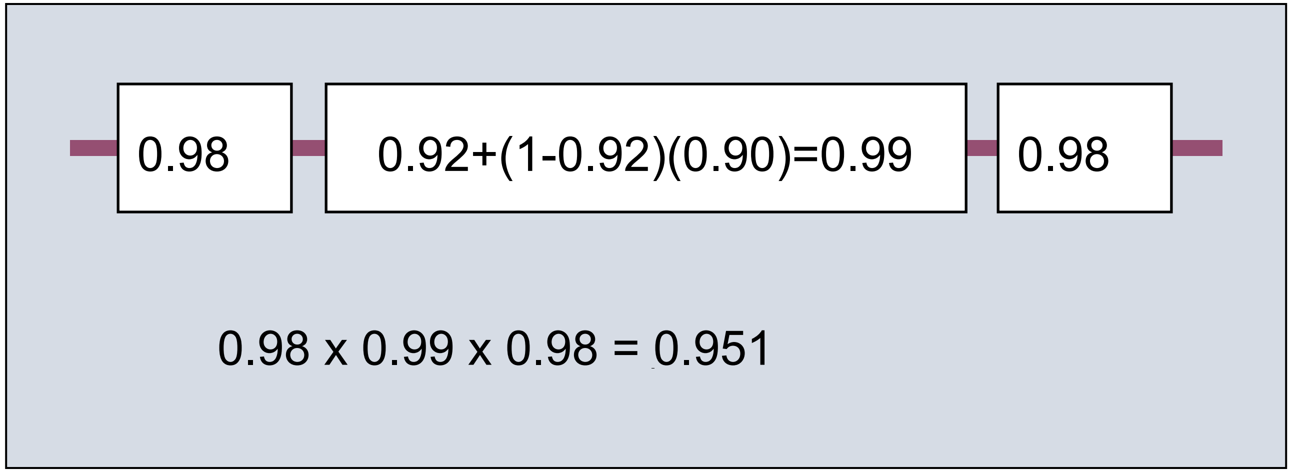
$$0.95 + 0.90(1-0.95) = 0.995$$

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?

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

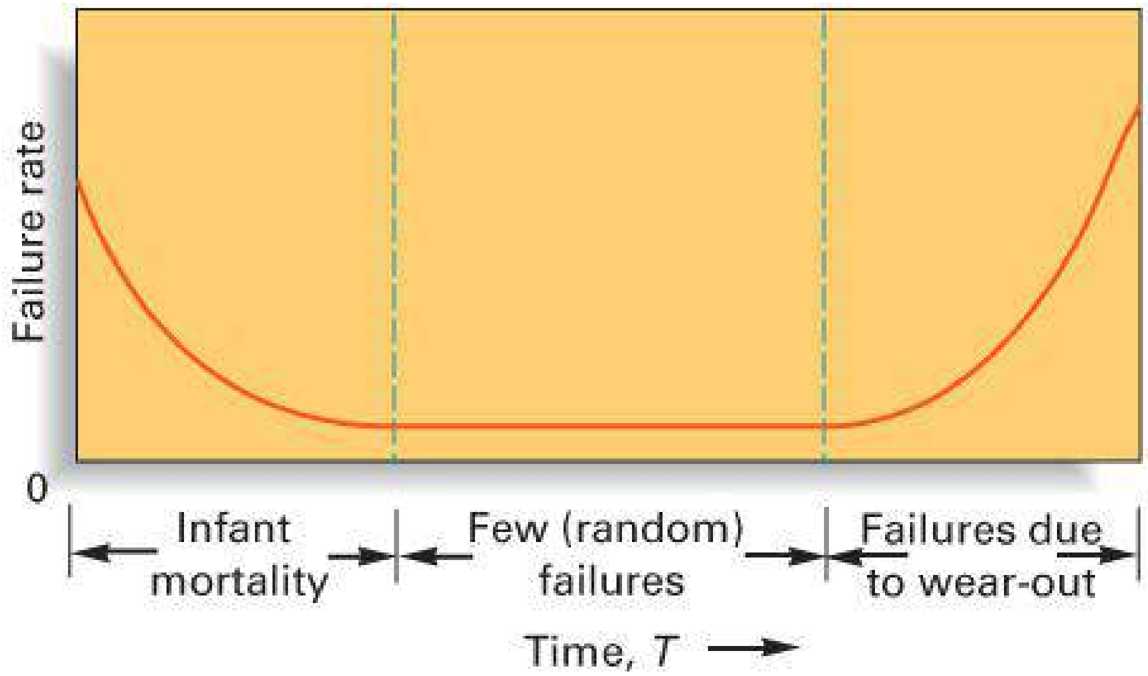
Reliability

- **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

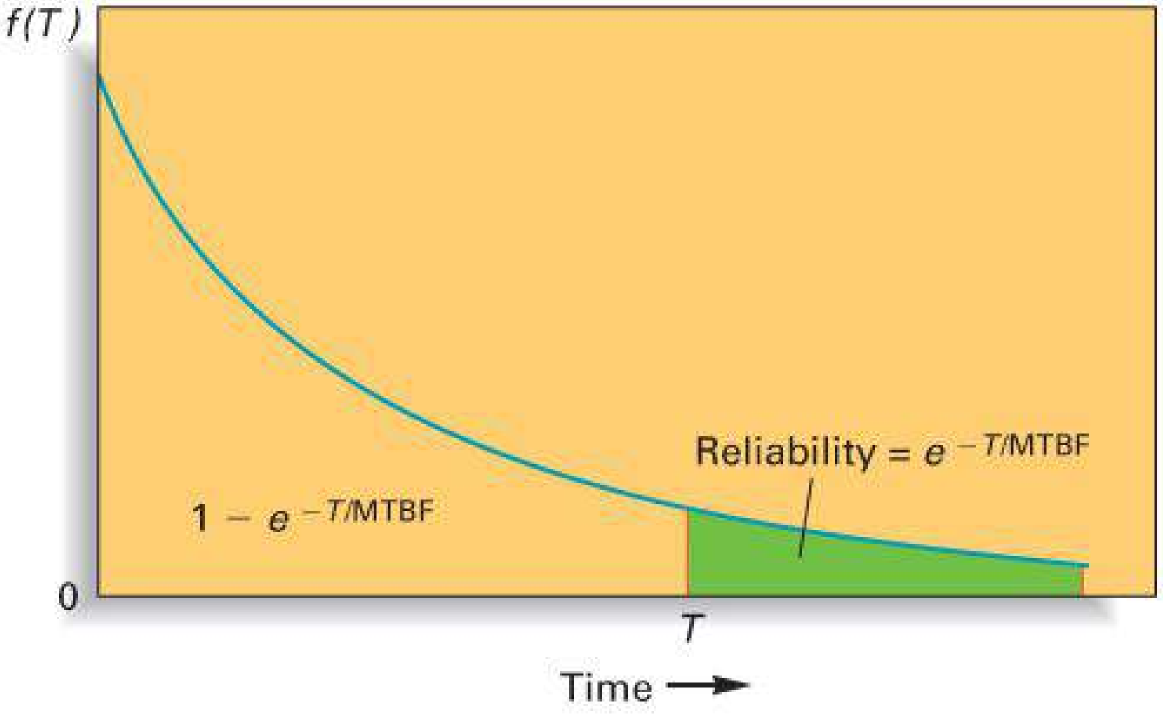
The Bathtub Curve



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

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?

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

From Table 4S.1, $e^{-1} = .3679$

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

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

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

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

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%

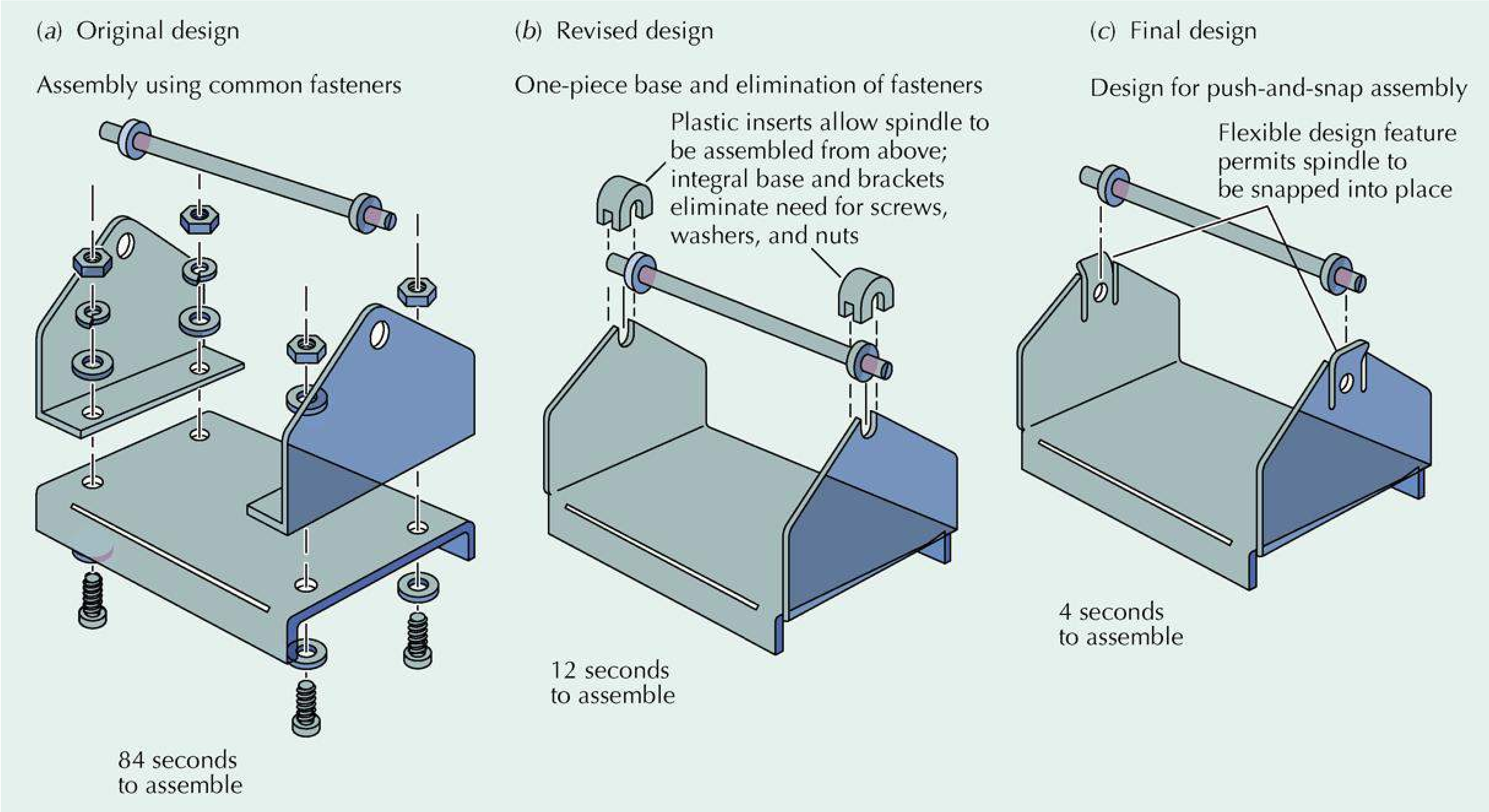
Usability

- 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

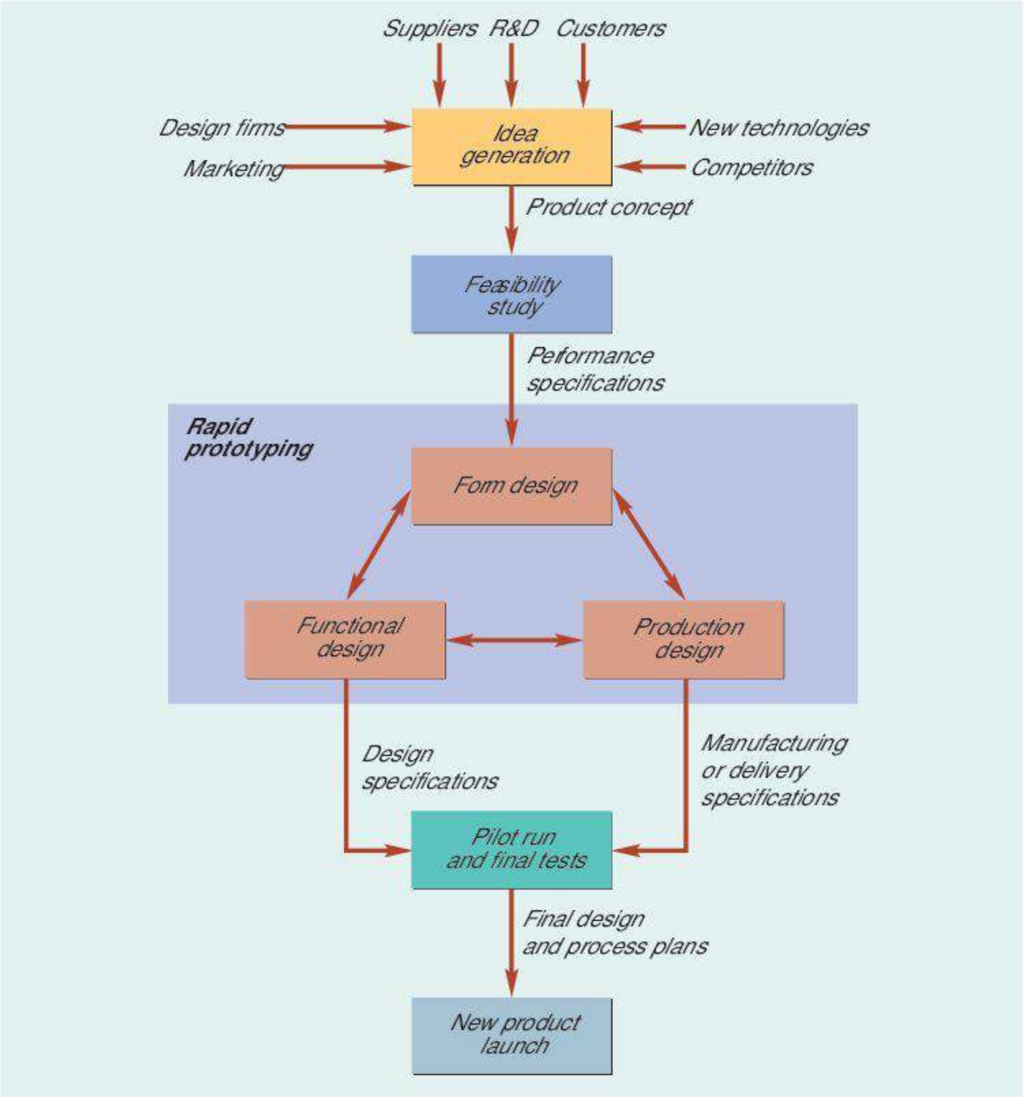
Production Design

- 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

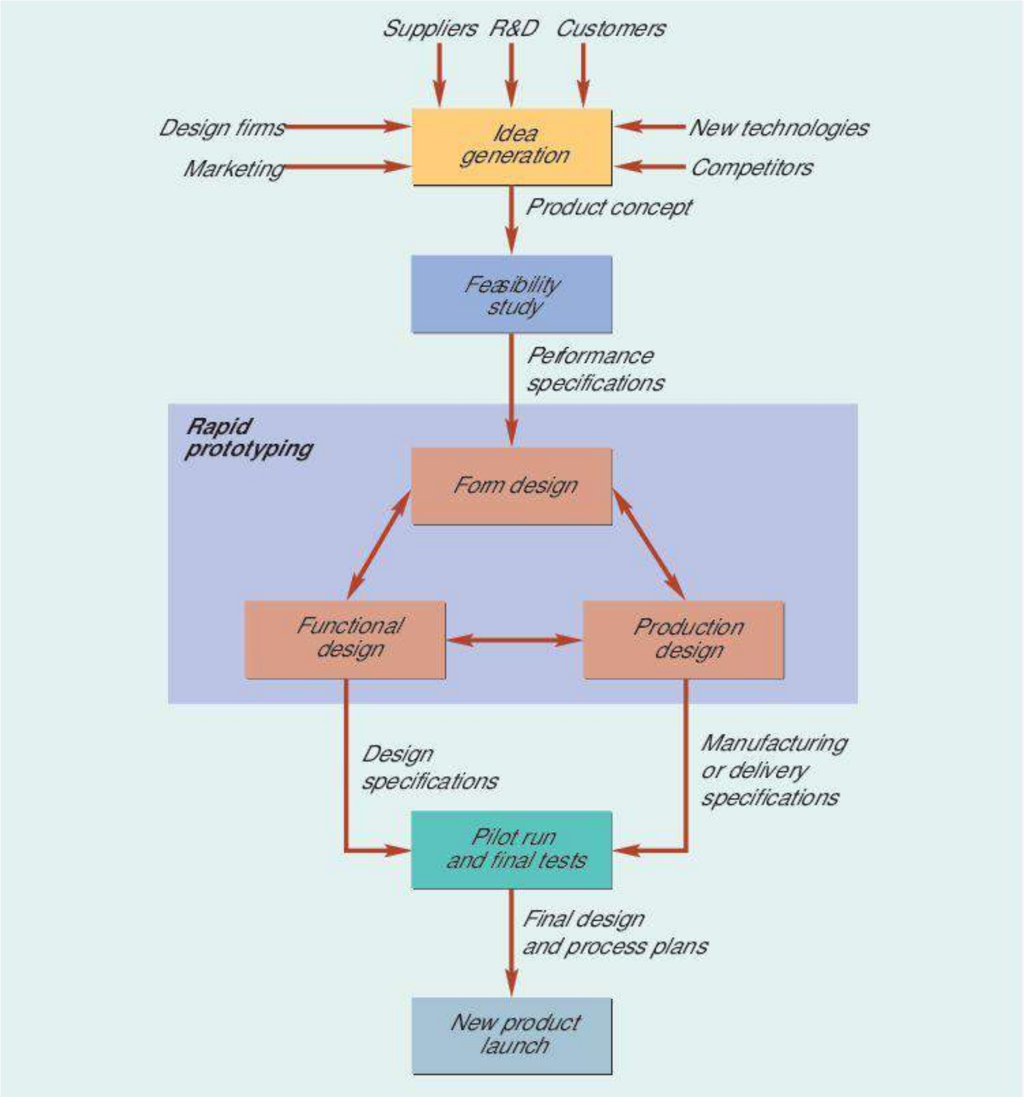
Technology in Design

- 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



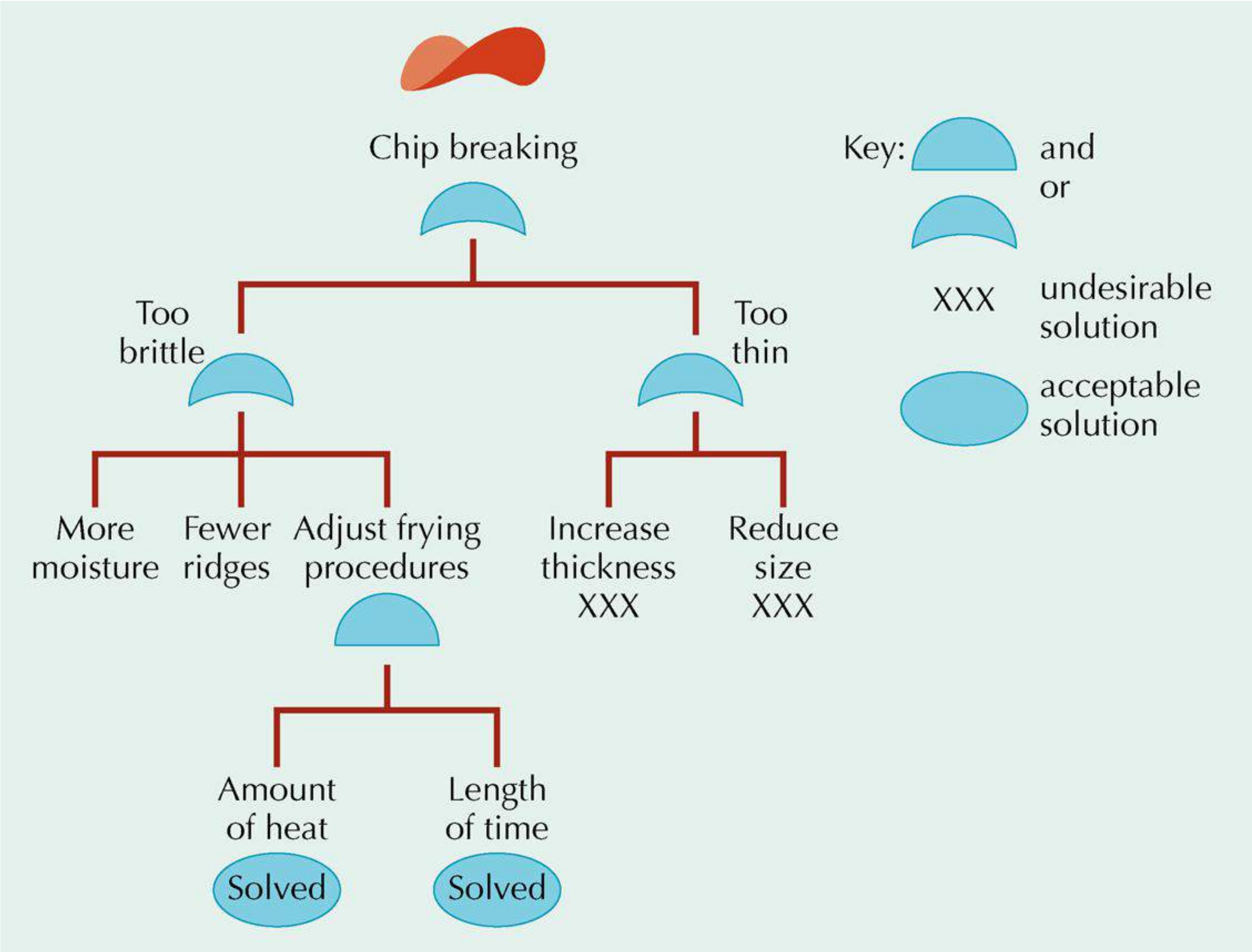
Design Quality Review

- 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)

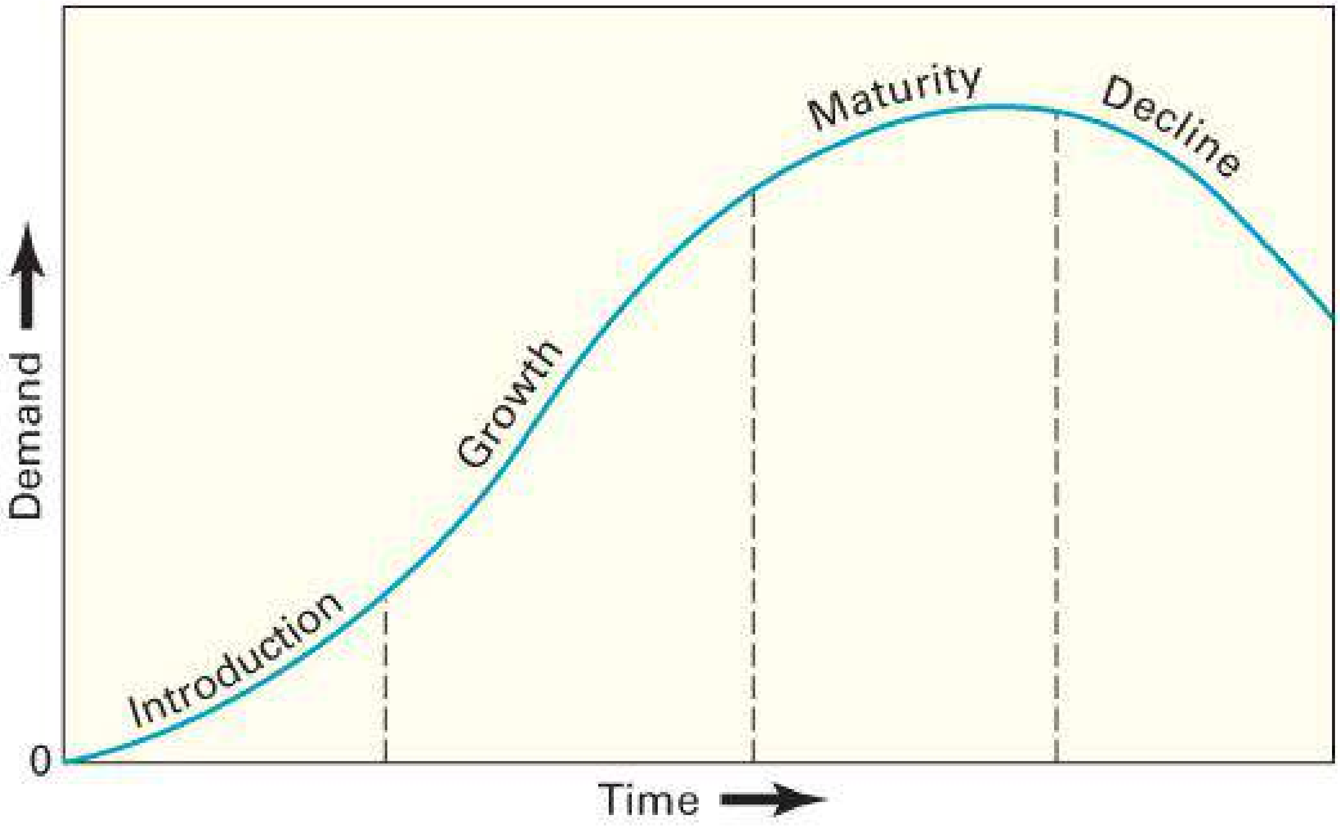


Value Analysis (VA)

- 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

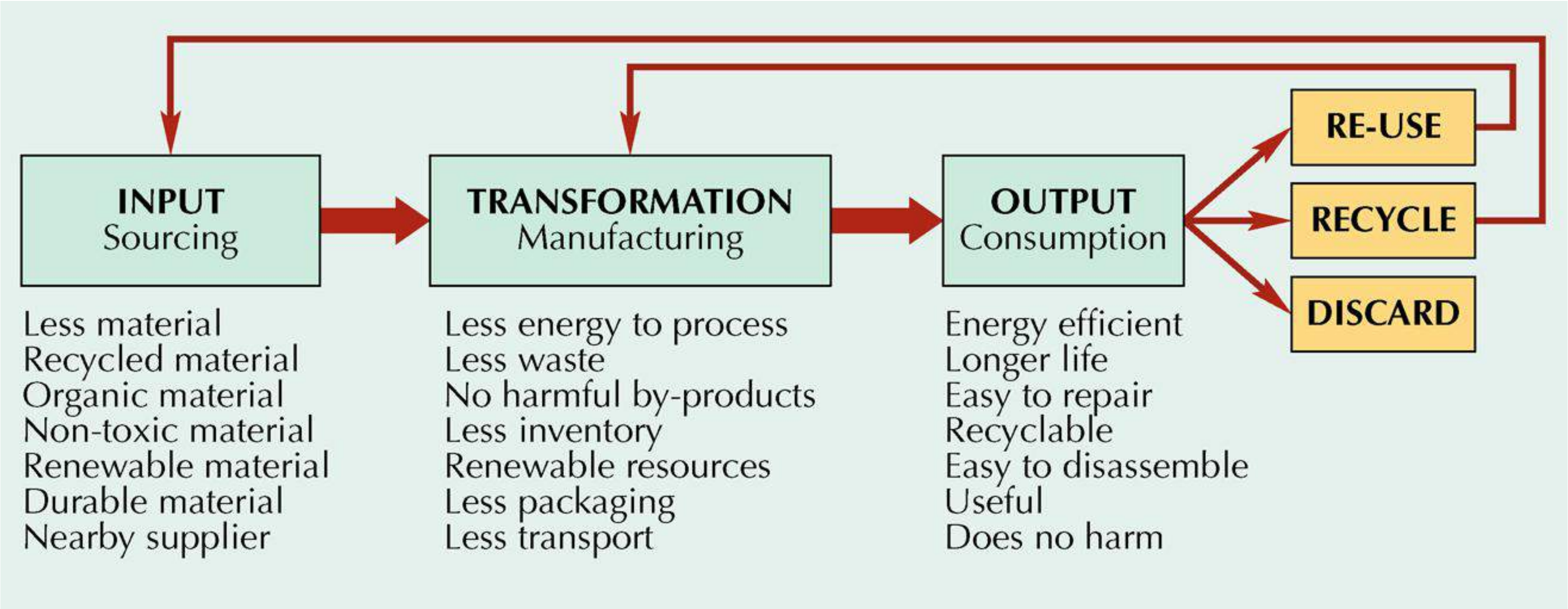
Product or service life stages



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

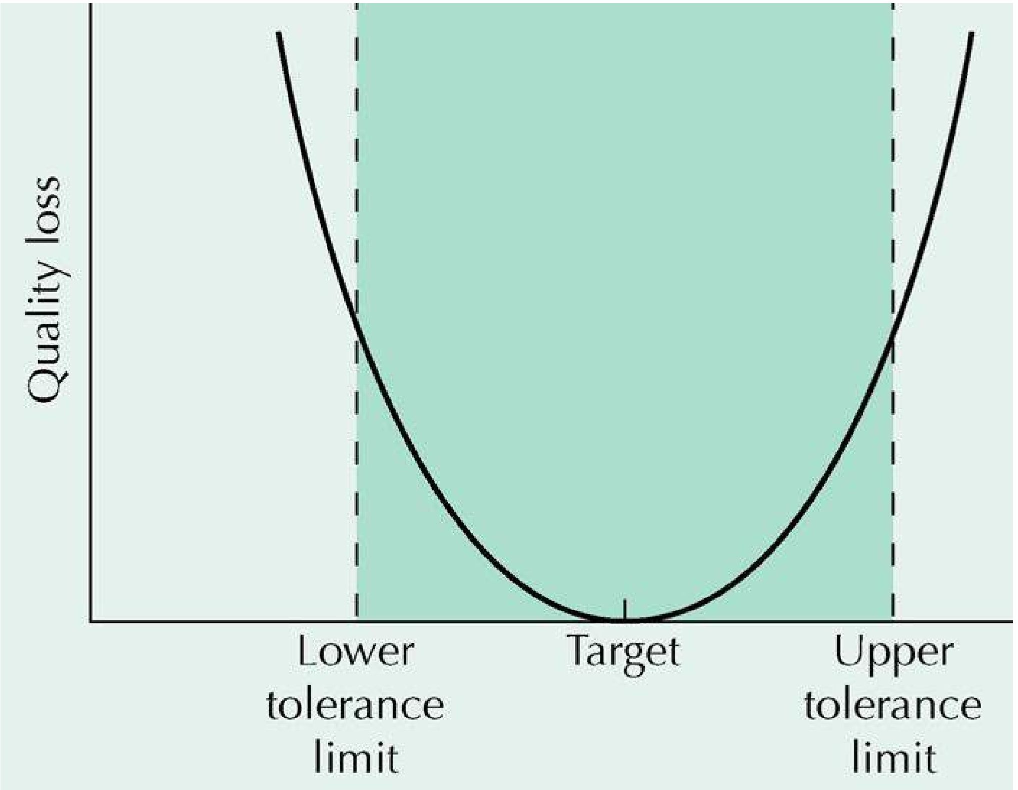
- Robust product
  - designed to withstand variations in environmental and operating conditions
- Robust design
  - yields a product or service designed to withstand variations
- Controllable factors
  - design parameters such as material used, dimensions, and form of processing
- Uncontrollable factors
  - 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)



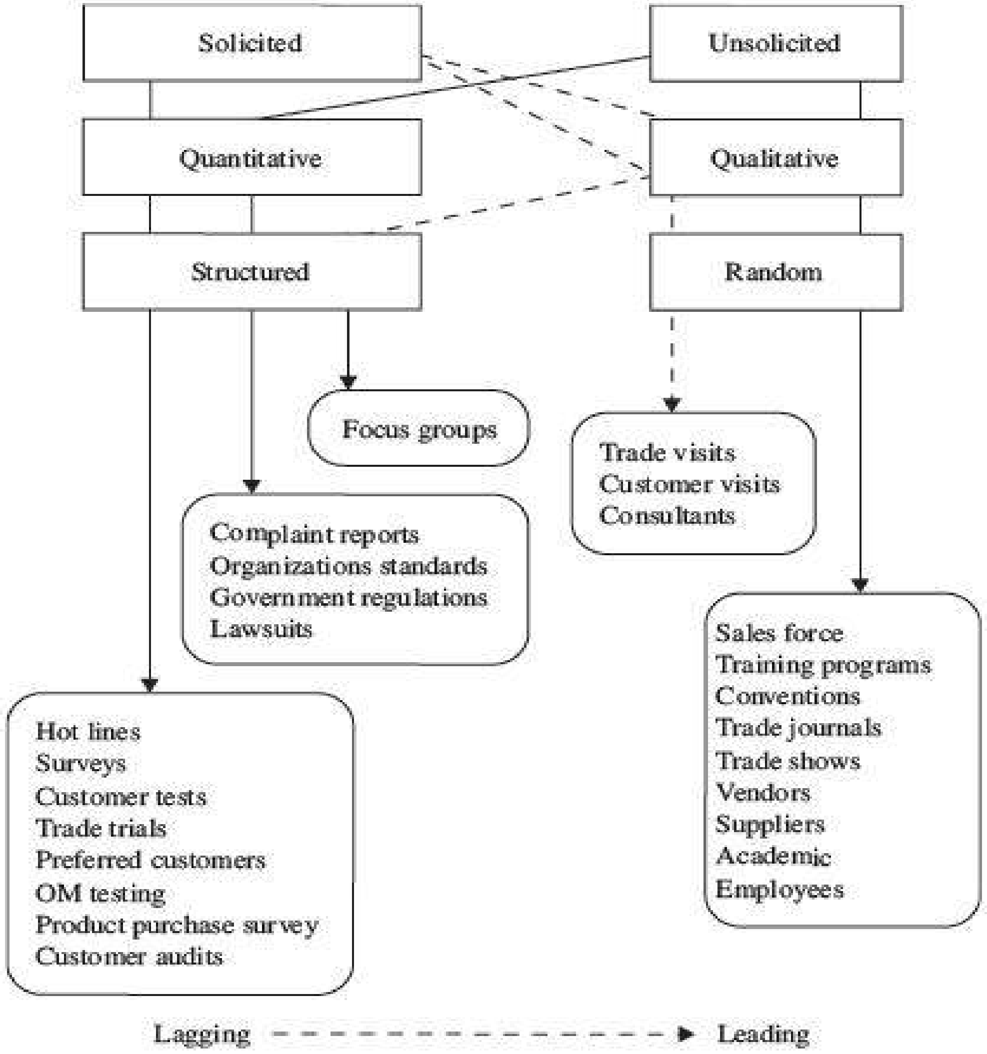
Green Areas

- Green Sourcing
  - use less material
  - use recycled if possible
- Green Manufacture
  - is energy from renewable sources
  - amount of waste produced
- Green Consumption
  - product’s use of energy
  - is product recyclable and maintainable
- Recycling and Re-Use
  - design products to be recycled or re-used
  - save energy and money

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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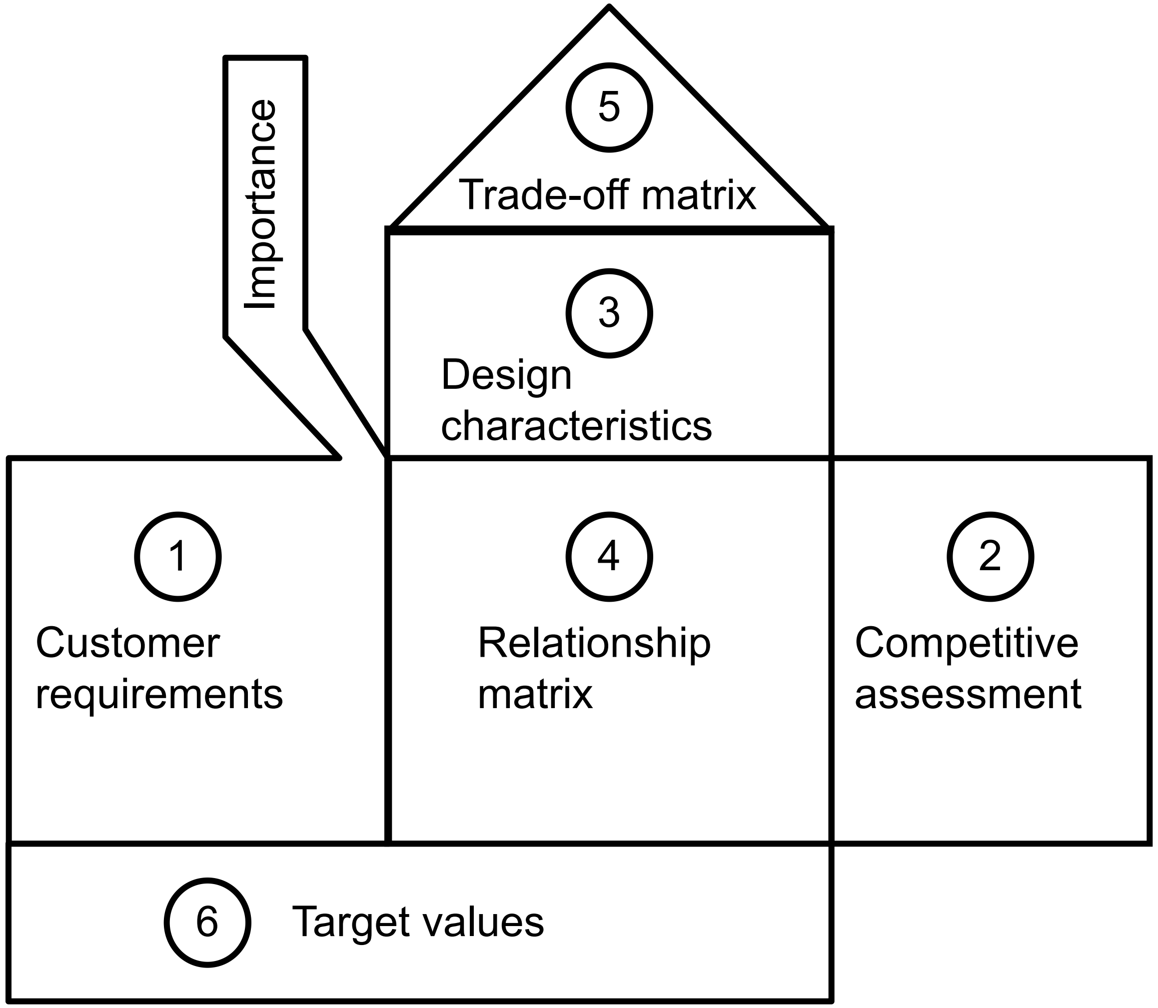
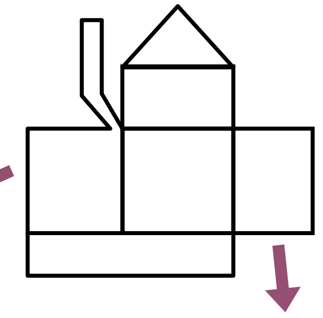
House of Quality

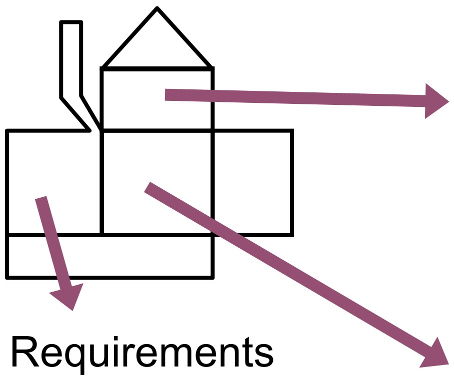


Competitive Assessment of Customer Requirements



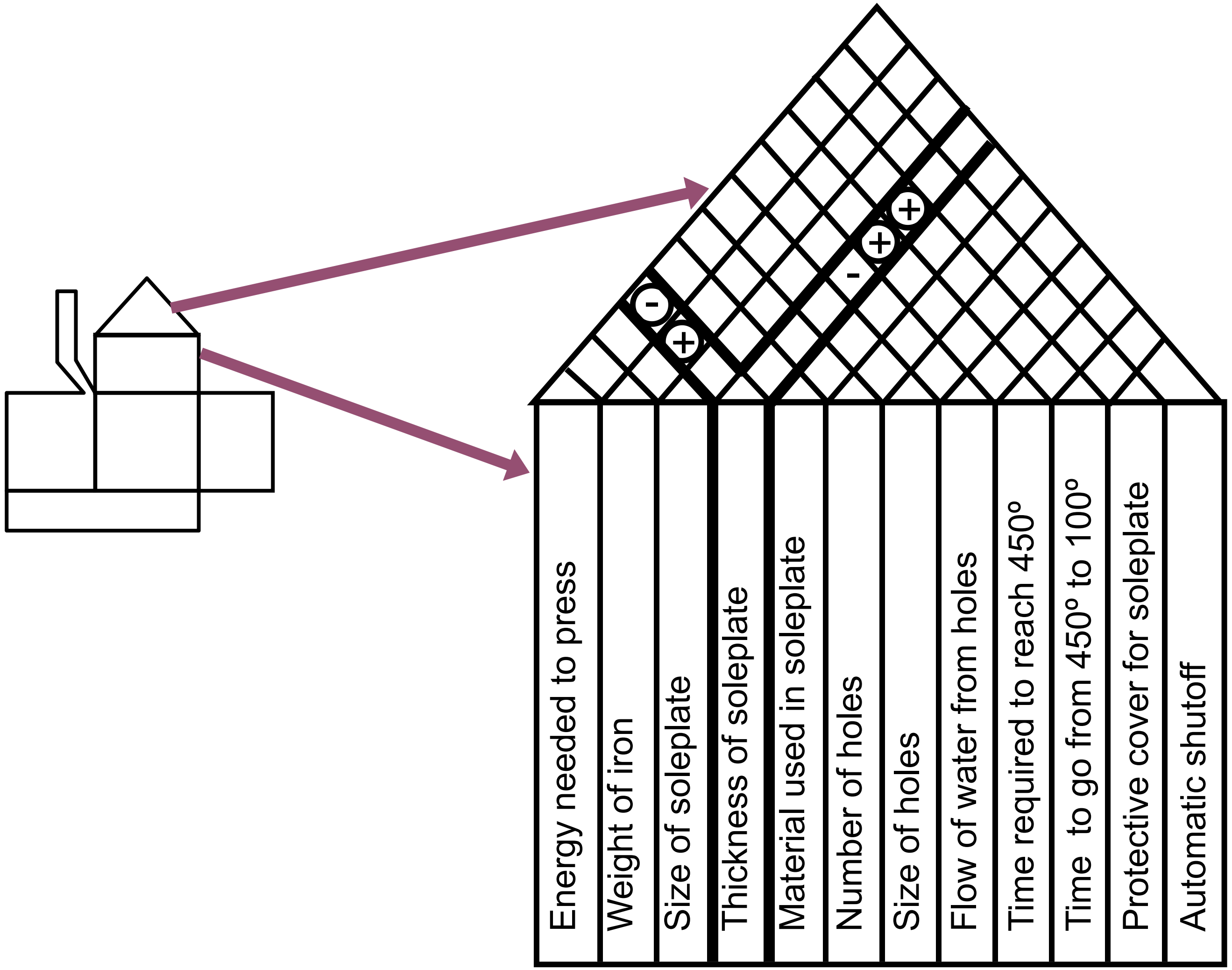
	Customer Requirements		Competitive Assessment 1	2	3	4	5
Irons well	Presses quickly	9		B A	X		
	Removes wrinkles	8		AB		X	
	Doesn't stick to fabric	6		X		BA	
	Provides enough steam	8			AB		X
	Doesn't spot fabric	6			X AB		
	Doesn't scorch fabric	9			A XB		
Easy and safe to use	Heats quickly	6		X	B	A	
	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

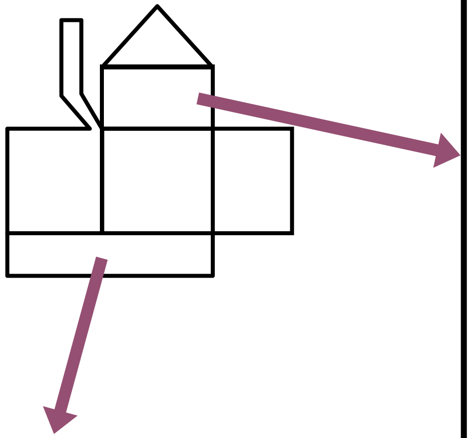


	Customer Requirements	Energy needed to press	Weight of iron	Size of soleplate	Thickness of soleplate	Material used in soleplate	Number of holes	Size of holes	Flow of water from holes	Time required to reach 450° F	Time to go from 450° to 100°	Protective cover for soleplate	Automatic shutoff
Irons well	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

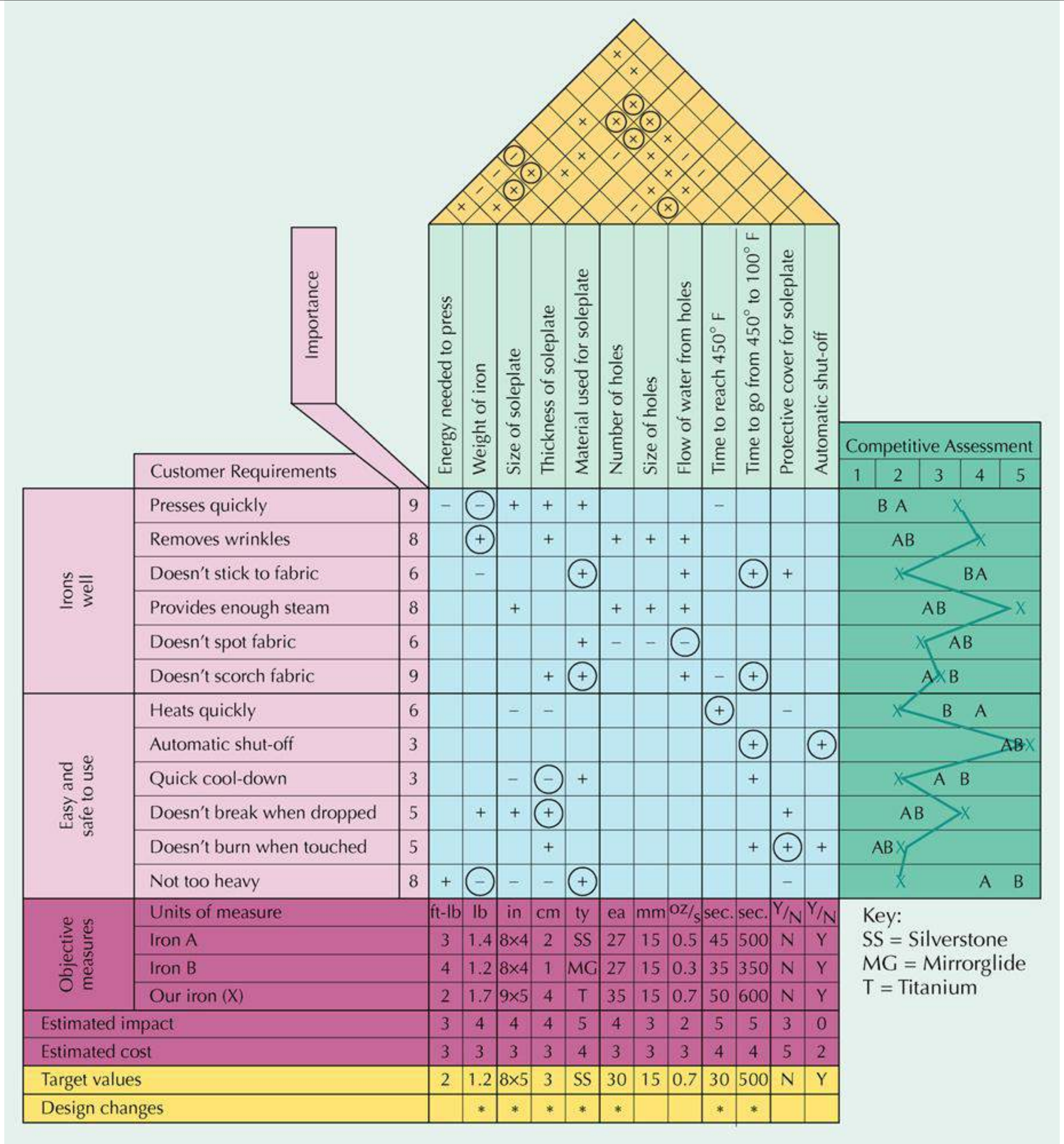


Targeted Changes in Design

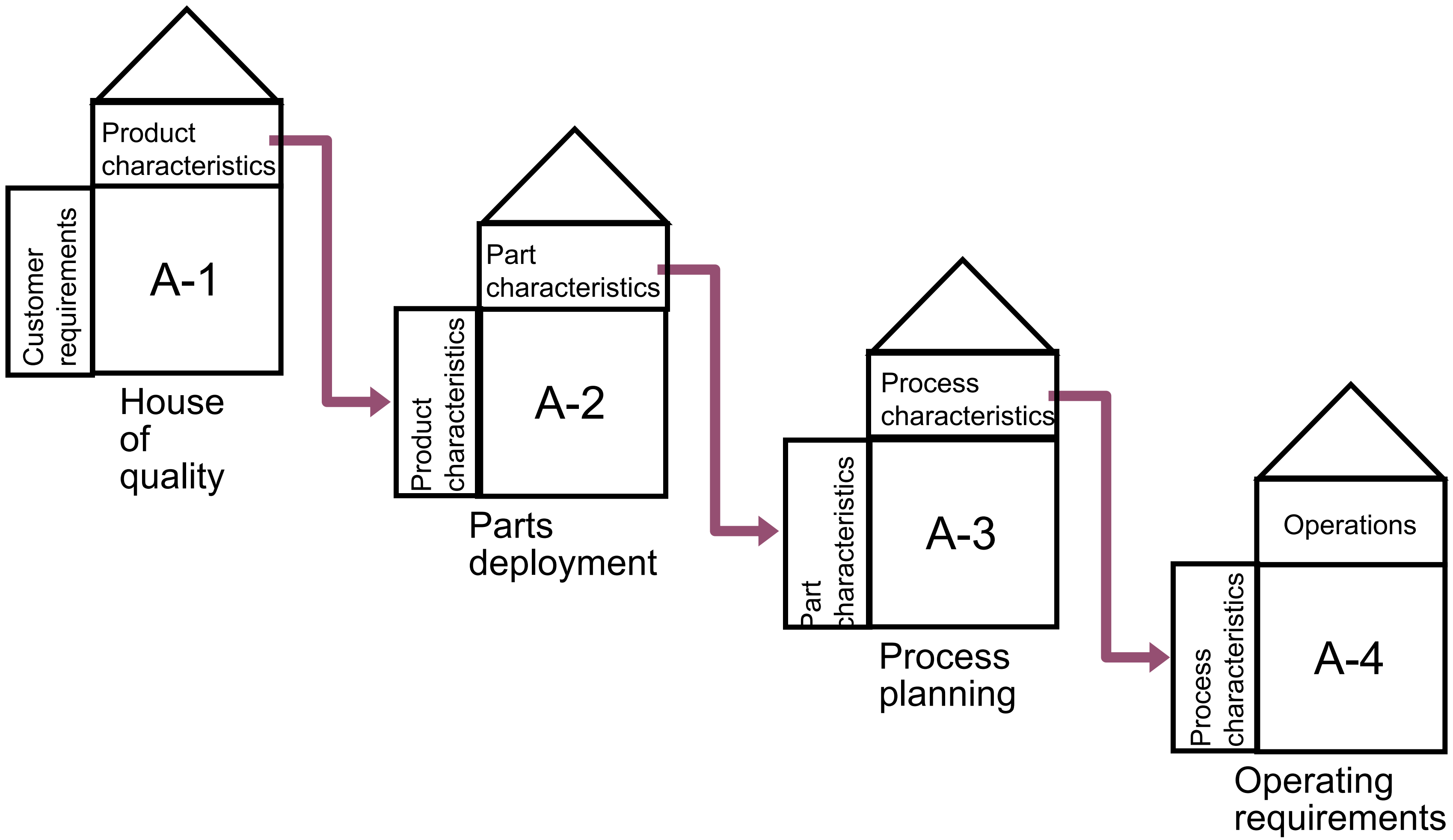


		Energy needed to press	Weight of iron	Size of soleplate	Thickness of soleplate	Material used in soleplate	Number of holes	Size of holes	Flow of water from holes	Time required to reach 450º	Time to go from 450º to 100º	Protective cover for soleplate	Automatic shutoff
Objective measures	Units of measure	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

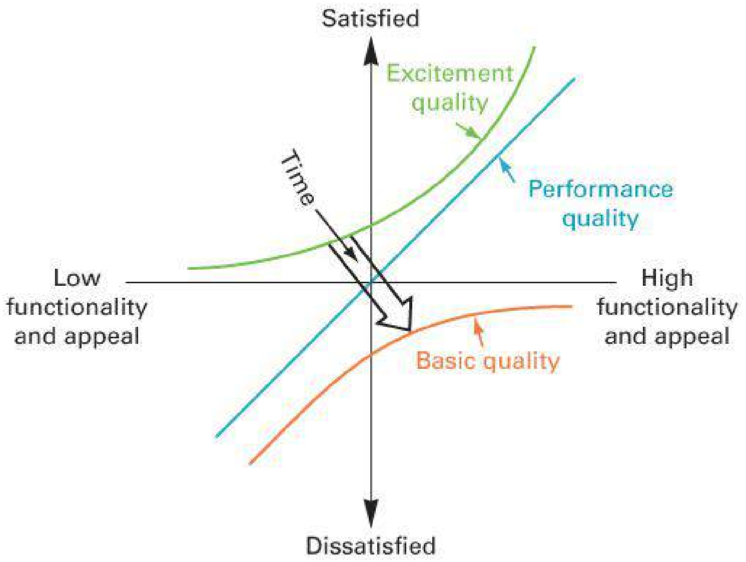
- Involves manufacturing in design process

- Provides documentation of design process

Kano Model

- **Basic quality**
  - Refers to customer requirements that have only limited effect on customer satisfaction if present, but lead to dissatisfaction if absent
- **Performance quality**
  - Refers to customer requirements that generate satisfaction or dissatisfaction in proportion to their level of functionality and appeal
- **Excitement quality**
  - Refers to a feature or attribute that was unexpected by the customer and causes excitement

The Kano Model – As Time Passes



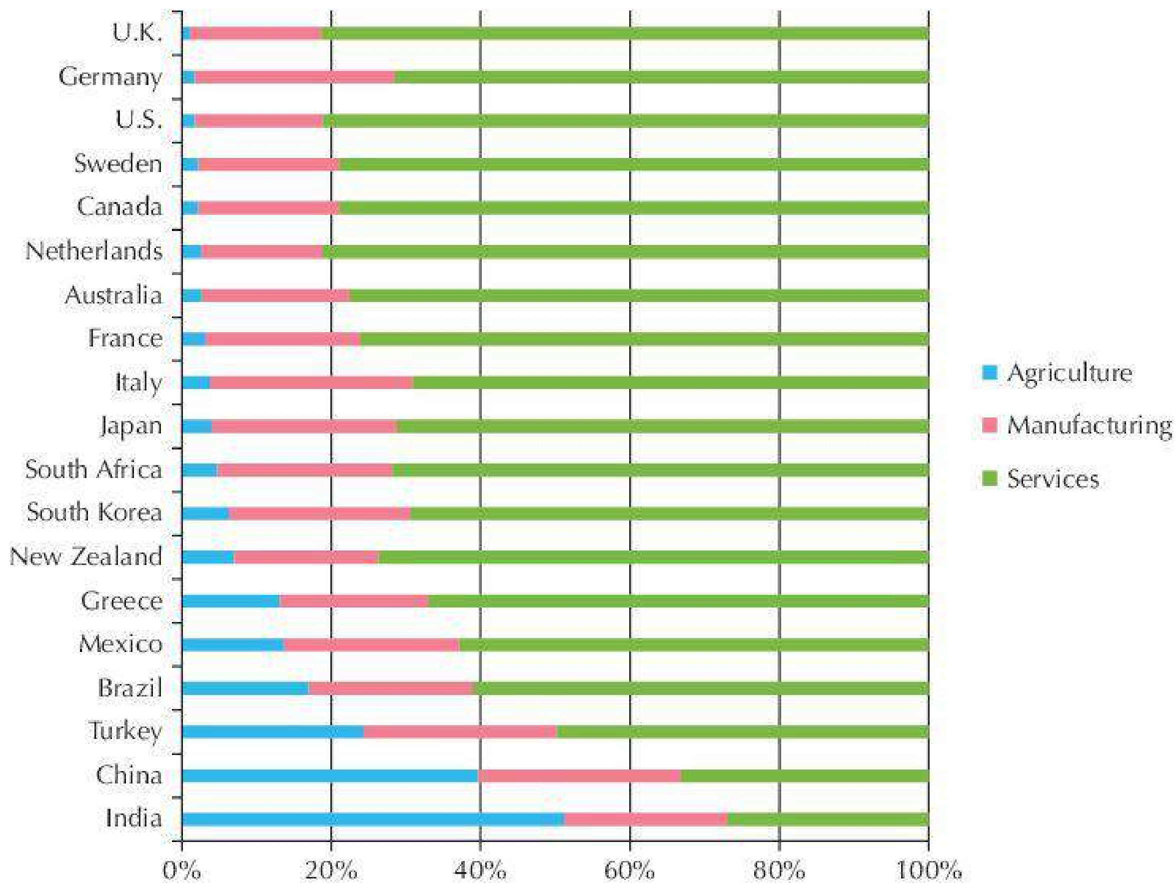
Service Design

Lecture Outline

- Service Economy
- Characteristics of Services
- Service Design Process
- Tools for Service Design
- Waiting Line Analysis for Service Improvement

Service Economy

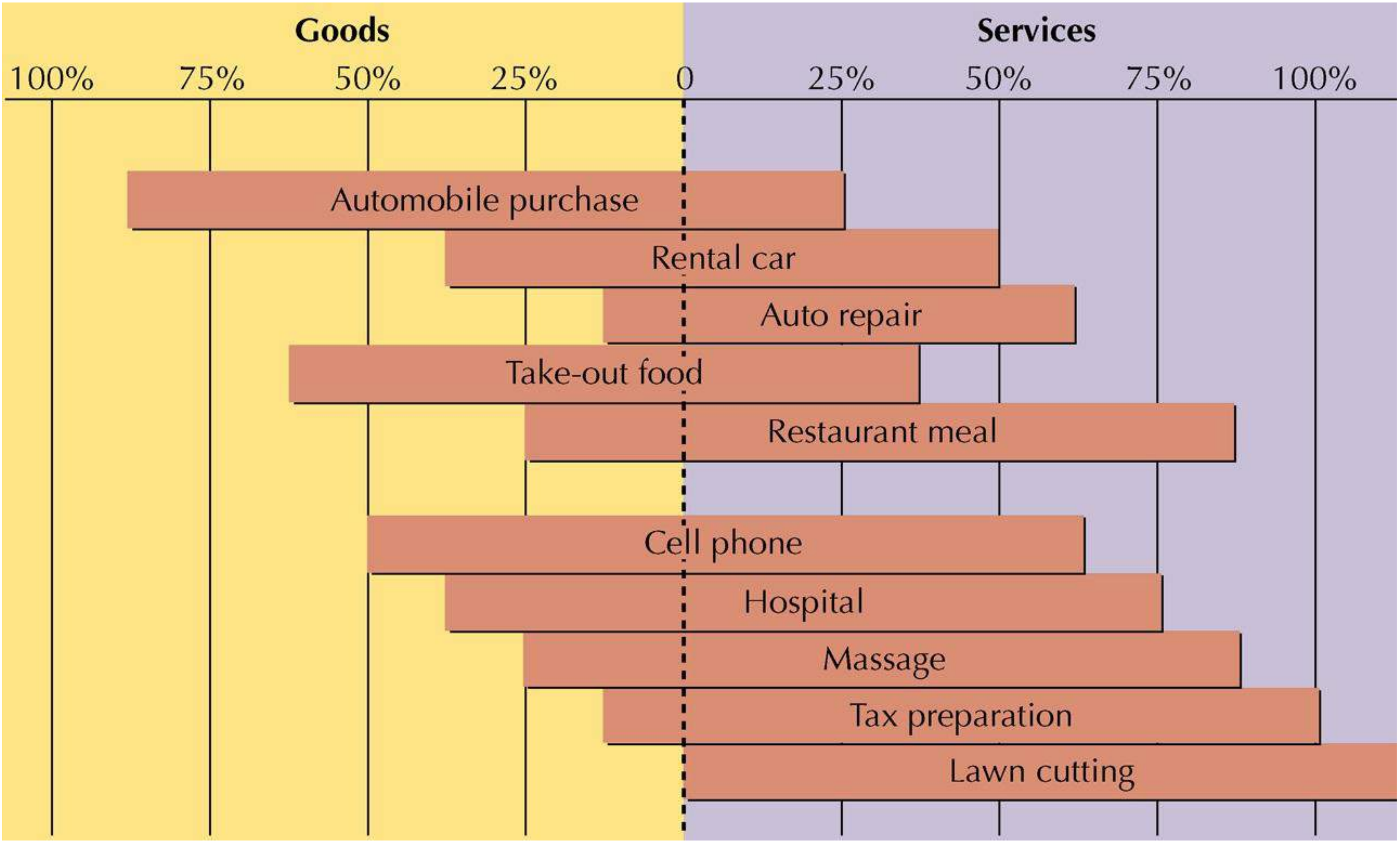
International Employment by Industry Sector



Characteristics of Services

- Services
  - acts, deeds, or performances
- Goods
  - tangible objects
- Facilitating services
  - accompany almost all purchases of goods
- Facilitating goods
  - accompany almost all service purchases

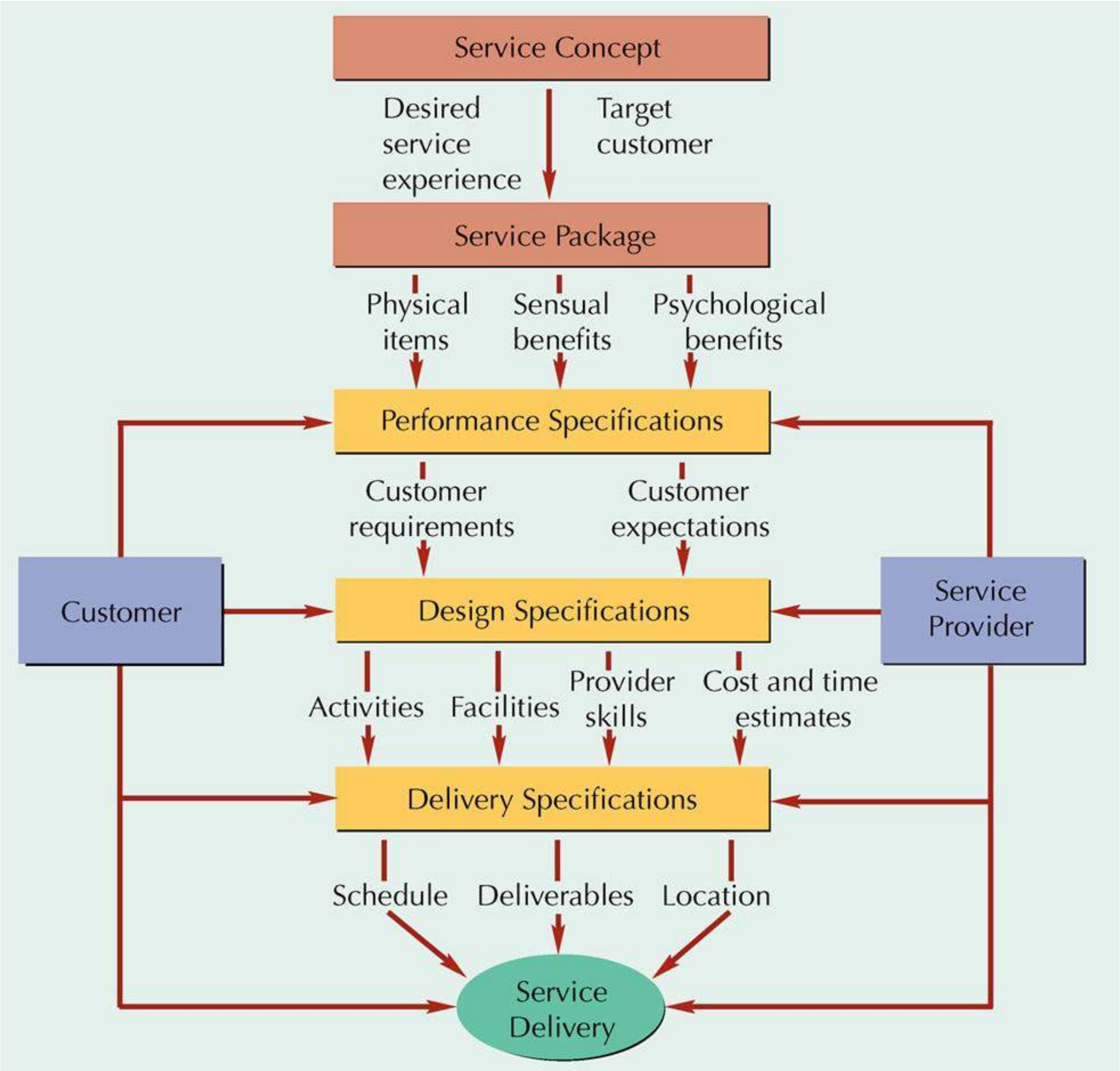
Continuum From Goods to Services



Characteristics of Services

- Services are intangible
- Service output is variable
- Services have higher customer contact
- Services are perishable
- The service and the service delivery are inseparable
- Services tend to be decentralized and geographically dispersed
- Services are consumed more often than products
- Services can be easily emulated

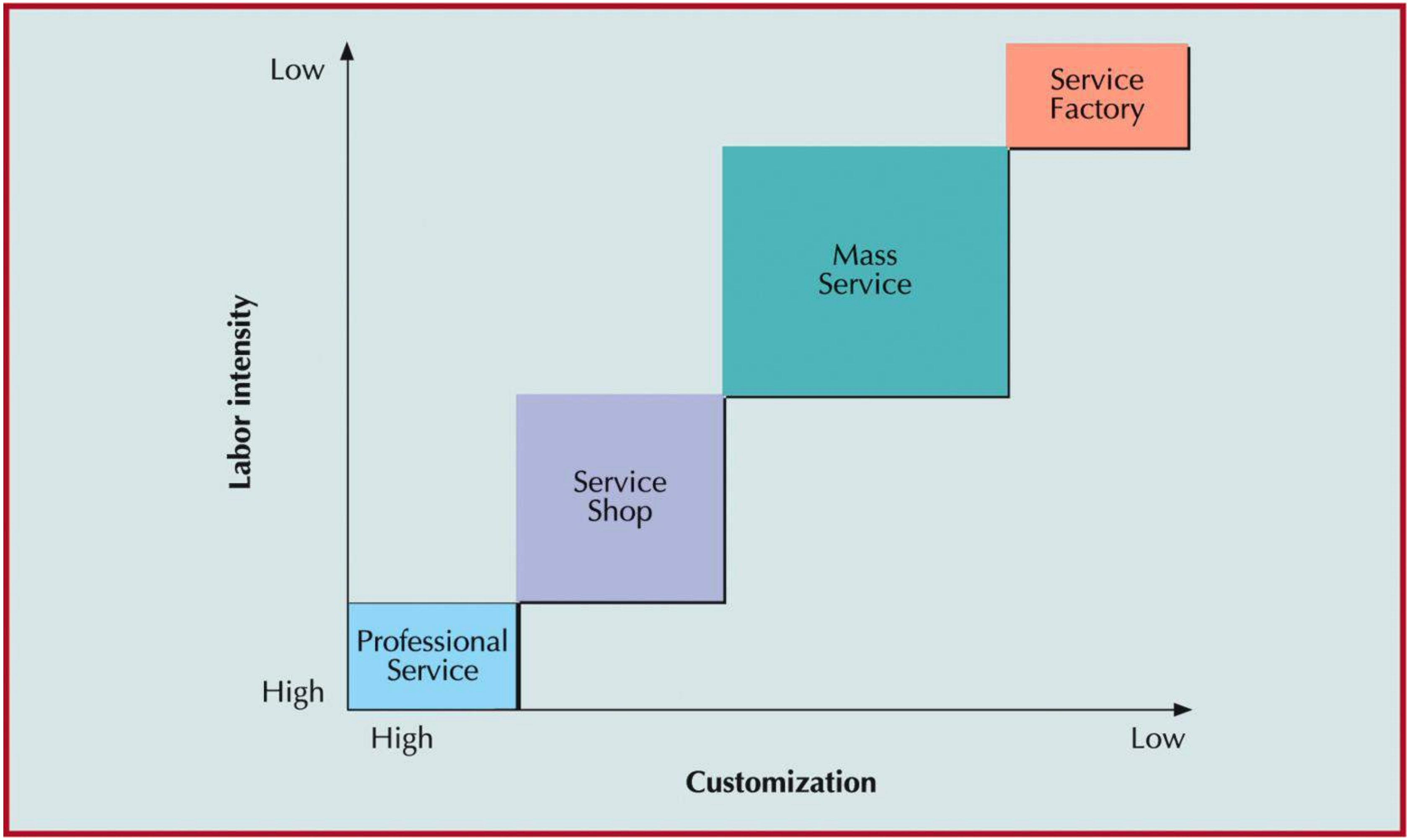
Service Design Process



Service Design Process

- Service concept
  - purpose of a service; it defines target market and customer experience
- Service package
  - mixture of physical items, sensual benefits, and psychological benefits
- Service specifications
  - performance specifications
  - design specifications
  - delivery specifications

Service Process Matrix



High vs. Low Contact Services

Design Decision	High-Contact Service	Low-Contact Service
▪ Facility location	▪ Convenient to customer	▪ Near labor or transportation source
▪ Facility layout	▪ Must look presentable, accommodate customer needs, and facilitate interaction with customer	▪ Designed for efficiency

High vs. Low Contact Services

Design Decision	High-Contact Service	Low-Contact Service
▪ Quality control	▪ More variable since customer is involved in process; customer expectations and perceptions of quality may differ; customer present when defects occur	▪ Measured against established standards; testing and rework possible to correct defects
▪ Capacity	▪ Excess capacity required to handle peaks in demand	▪ Planned for average demand

High vs. Low Contact Services

Design Decision	High-Contact Service	Low-Contact Service
▪ Worker skills	▪ Must be able to interact well with customers and use judgment in decision making	▪ Technical skills
▪ Scheduling	▪ Must accommodate customer schedule	▪ Customer concerned only with completion date

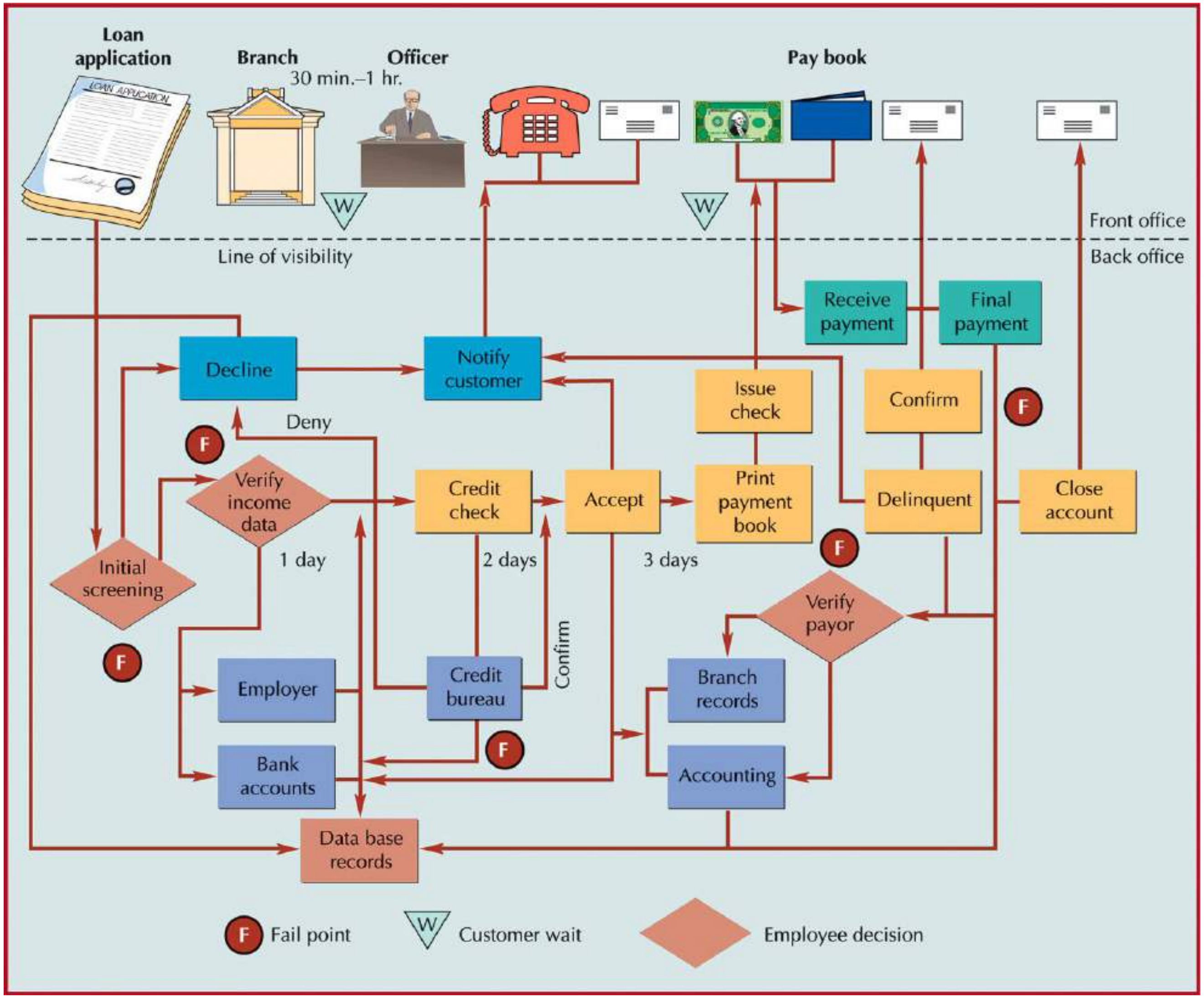
High vs. Low Contact Services

Design Decision	High-Contact Service	Low-Contact Service
▪ Service process	▪ Mostly front-room activities; service may change during delivery in response to customer	▪ Mostly back-room activities; planned and executed with minimal interference
▪ Service package	▪ Varies with customer; includes environment as well as actual service	▪ Fixed, less extensive

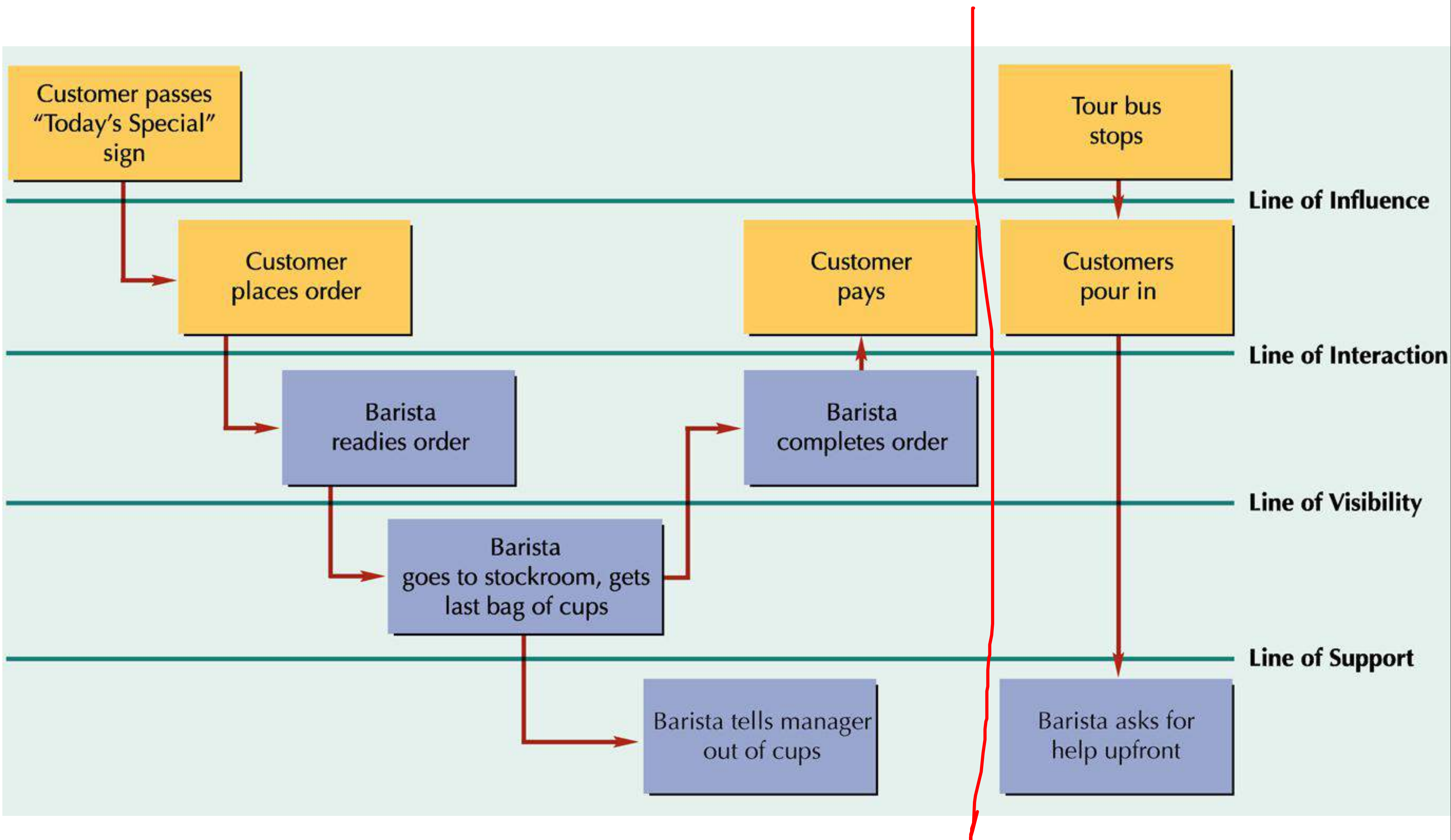
Tools for Service Design

- Service blueprinting
  - line of influence
  - line of interaction
  - line of visibility
  - line of support
- Front-office/Back-office activities
- Servicescapes
  - space and function
  - ambient conditions
  - signs, symbols, and artifacts
- Quantitative techniques

Service Blueprinting

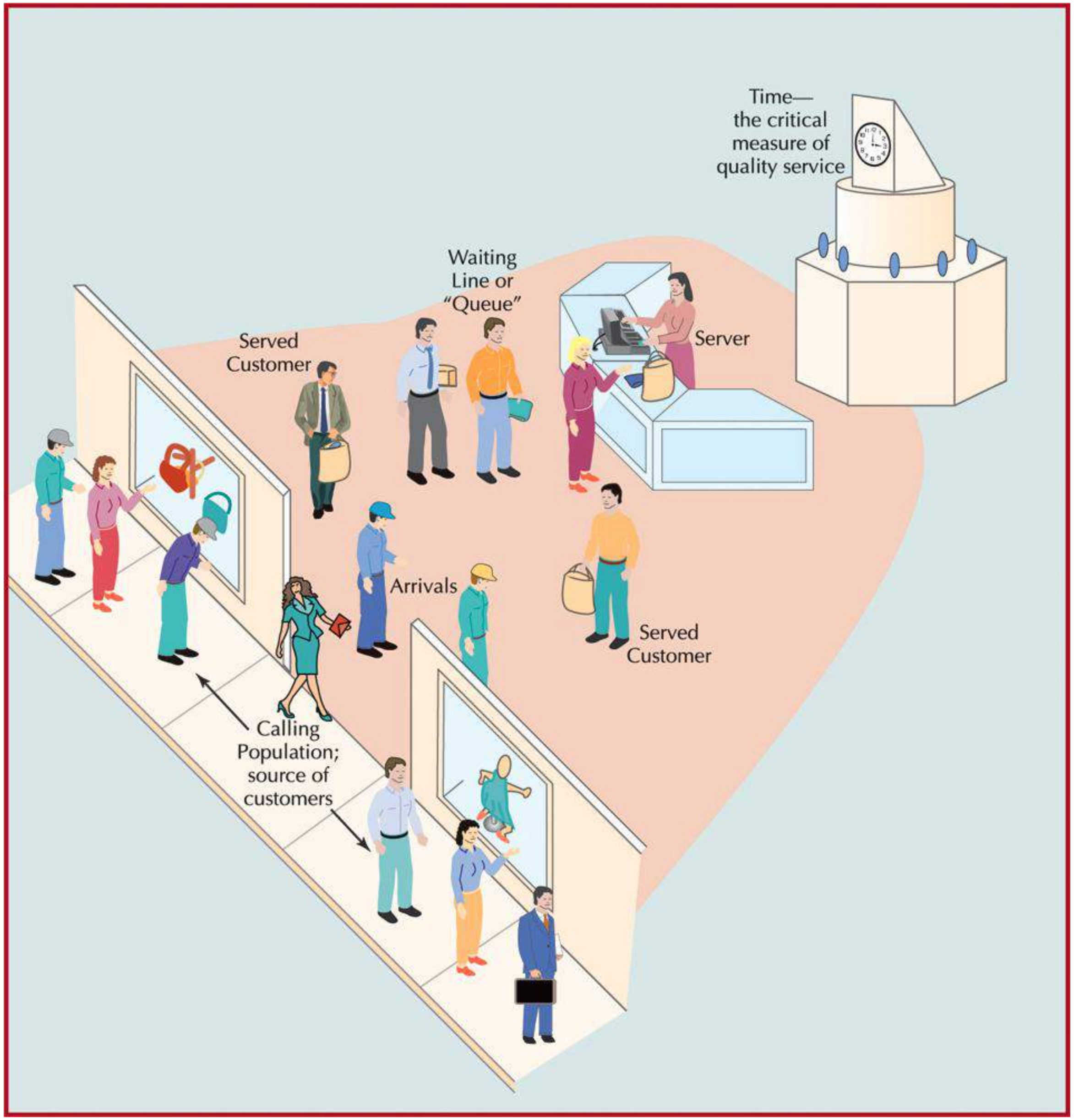


Service Blueprinting

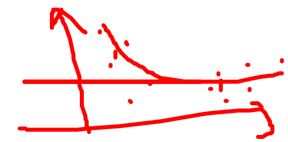


Elements of Waiting Line Analysis

- Operating characteristics
  - average values for characteristics that describe performance of waiting line system
- Queue
  - a single waiting line
- Waiting line system
  - consists of arrivals, servers, and waiting line structure
- Calling population
  - source of customers; infinite or finite


Time—
the critical
measure of
quality service
Waiting
Line or
"Queue"
Server
Served
Customer
Arrivals
Served
Customer
Calling
Population;
source of
customers

Elements of Waiting Line Analysis



- Arrival rate (λ)
  - frequency at which customers arrive at a waiting line according to a probability distribution, usually Poisson
- Service rate (μ)
  - time required to serve a customer, usually described by negative exponential distribution
- Service rate must be higher than arrival rate (λ < μ)
- Queue discipline
  - order in which customers are served
- Infinite queue
  - can be of any length; length of a **finite** queue is limited

Elements of Waiting Line Analysis

(b) Multiple-server waiting line

(a) Single-server waiting line

- Channels
  - number of parallel servers for servicing customers
- Phases
  - number of servers in sequence a customer must go through

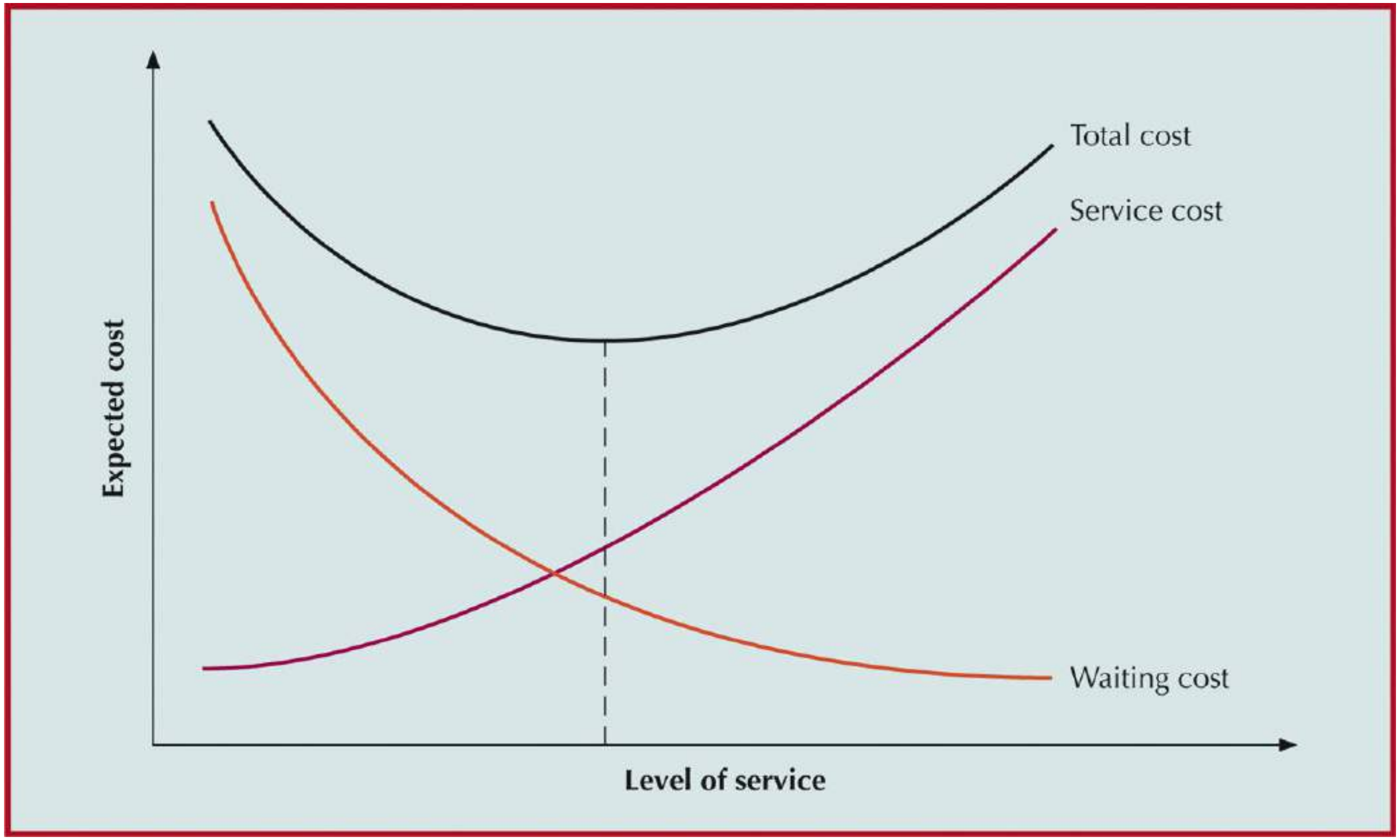
Operating Characteristics

- *Operating characteristics* are assumed to approach a *steady state*

Notation	Operating Characteristic
L	Average number of customers in the system (waiting and being served)
L_q	Average number of customers in the waiting line
W	Average time a customer spends in the system (waiting and being served)
W_q	Average time a customer spends waiting in line
P_0	Probability of no (i.e., zero) customers in the system
P_n	Probability of *n* customers in the system
ρ	Utilization rate; the proportion of time the system is in use

Traditional Cost Relationships

- As service improves, cost increases



Psychology of Waiting

- Waiting rooms
  - magazines and newspapers
  - televisions
- Bank of America
  - mirrors
- Supermarkets
  - magazines
  - “impulse purchases”

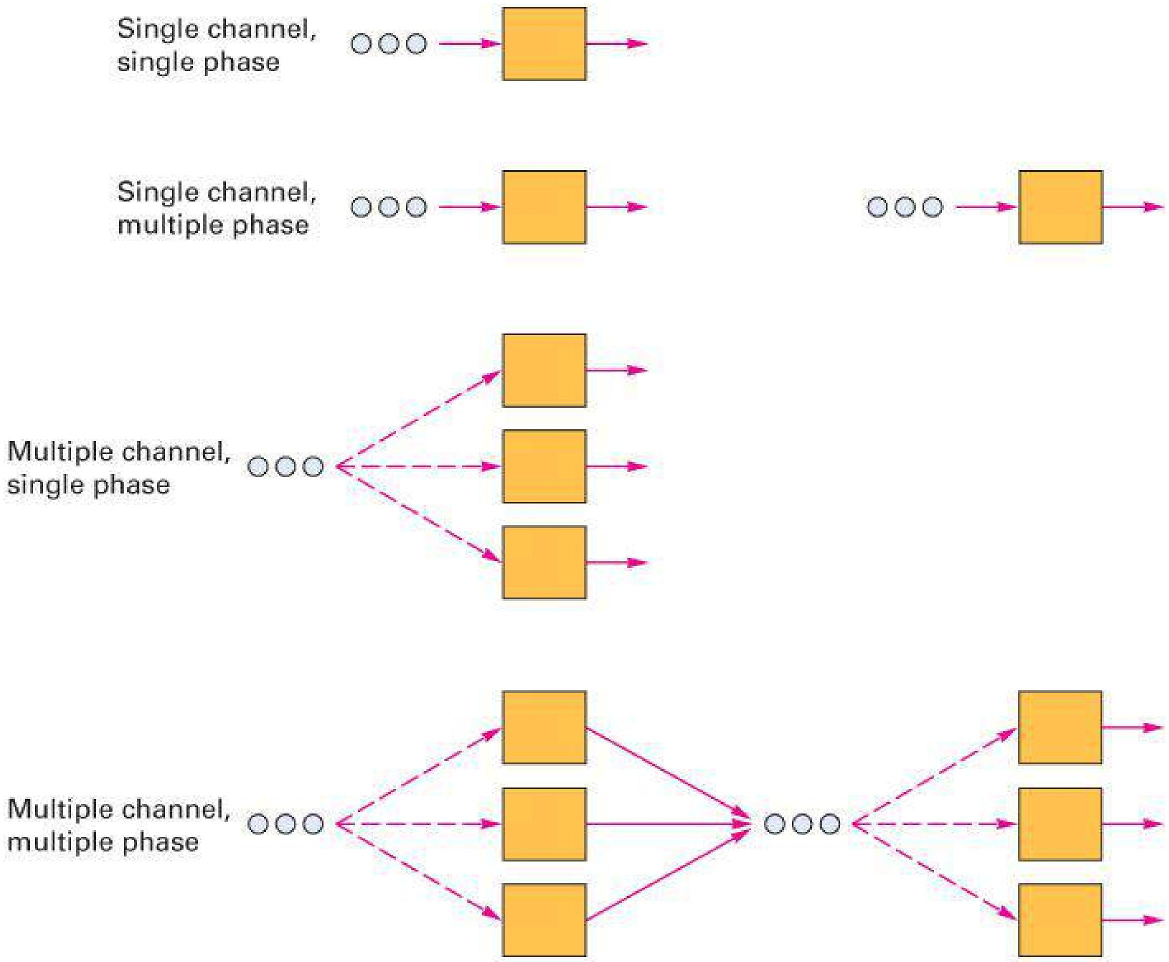
Psychology of Waiting

- Preferential treatment
  - Grocery stores: express lanes for customers with few purchases
  - Airlines/Car rental agencies: special cards available to frequent-users or for an additional fee
  - Phone retailers: route calls to more or less experienced salespeople based on customer's sales history
- Critical service providers
  - services of police department, fire department, etc.
  - waiting is unacceptable; cost is not important

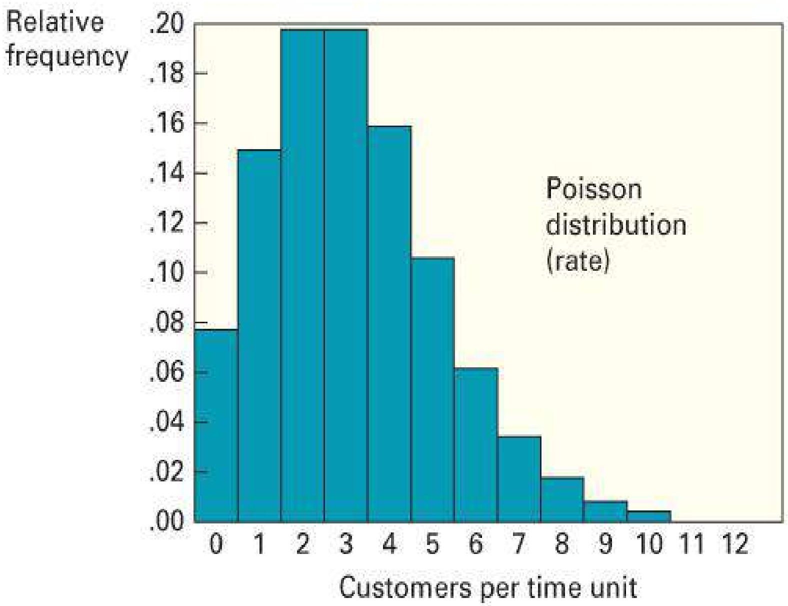
Waiting Line Models

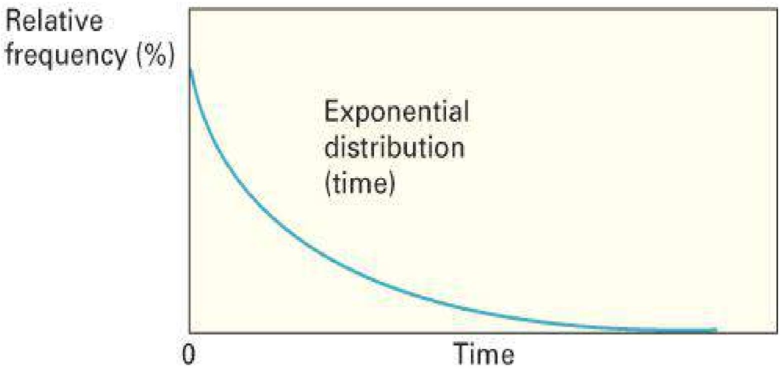
- *Single-server* model
  - simplest, most basic waiting line structure
- Frequent variations (all with Poisson arrival rate)
  - exponential service times
  - general (unknown) distribution of service times
  - constant service times
  - exponential service times with finite queue
  - exponential service times with finite calling population

Common Queuing Systems



Poisson and Negative Exponential





$$p_{(x)} = \frac{\lambda^x e^{-\lambda}}{x!}$$

Mean = λ

$$f(x) = \lambda e^{-\lambda x}$$

$$p_{(x \geq x_0)} = e^{-\lambda x_0}$$

Mean = $1/\lambda$

- Average arrival rate of 3.2 customers per hour. The arrival rate can be modelled by a Poisson distribution.

1. What is the probability of 5 customers arriving?

2. Probability of having more than 7 customers?

Arrivals at a bank are Poisson distributed with a mean of 1.2 customers every minute.

What is the average time between arrivals and what is the probability that at least 2 minutes will elapse between one arrival and the next arrival?

Basic Single-Server Model

- Assumptions
  - Poisson arrival rate
  - exponential service times
  - first-come, first-served queue discipline
  - infinite queue length
  - infinite calling population
- Computations
  - λ = mean arrival rate
  - μ = mean service rate
  - n = number of customers in line

Operating Characteristics

- *Operating characteristics* are assumed to approach a *steady state*

Notation	Operating Characteristic
L	Average number of customers in the system (waiting and being served)
L_q	Average number of customers in the waiting line
W	Average time a customer spends in the system (waiting and being served)
W_q	Average time a customer spends waiting in line
P_0	Probability of no (i.e., zero) customers in the system
P_n	Probability of *n* customers in the system
ρ	Utilization rate; the proportion of time the system is in use

Basic Single-Server Model

- probability that no customers are in queuing system

$$P_0 = \left(1 - \frac{\lambda}{\mu}\right)$$

- probability of *n* customers in queuing system

$$P_n = \left(\frac{\lambda}{\mu}\right)^n \cdot P_0 = \left(\frac{\lambda}{\mu}\right)^n \left(1 - \frac{\lambda}{\mu}\right)$$

- average number of customers in queuing system

$$L = \frac{\lambda}{\mu - \lambda}$$

- average number of customers in waiting line

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)}$$

Operating Characteristics

- *Operating characteristics* are assumed to approach a *steady state*

Notation	Operating Characteristic
L	Average number of customers in the system (waiting and being served)
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P_0	Probability of no (i.e., zero) customers in the system
P_n	Probability of *n* customers in the system
ρ	Utilization rate; the proportion of time the system is in use

Basic Single-Server Model

- average time customer spends in queuing system

$$W = \frac{1}{\mu - \lambda} = \frac{L}{\lambda}$$

- average time customer spends waiting in line

$$W_q = \frac{\lambda}{\mu\,(\mu - \lambda)}$$

- probability that server is busy and a customer has to wait (utilization factor)

$$\rho = \frac{\lambda}{\mu}$$

- probability that server is idle and customer can be served

$$I = 1 - \rho$$

$$= 1 - \frac{\lambda}{\mu} = P_0$$

Basic Single-Server Model Example

$\lambda = 24$

$\mu = 30$

$P_0 =$

$L=$

$L_q =$

Basic Single-Server Model Example

$\lambda = 24$

$\mu = 30$

$$P_0 = \left(1 - \frac{\lambda}{\mu}\right) = \left(1 - \frac{24}{30}\right)$$

$= 0.20$ probability of no customers in the system

$$L = \frac{\lambda}{\mu - \lambda} = \frac{24}{30 - 24}$$

$= 4$ customers on the average in the queuing system

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(24)^2}{30(30 - 24)}$$

$= 3.2$ customers on the average in the waiting line

Basic Single-Server Model Example

$W =$

$W_q =$

$\rho =$

$I =$

Basic Single-Server Model Example

$$W = \frac{1}{\mu - \lambda} = \frac{1}{30 - 24}$$

$= 0.167$ hour (10 minutes) average time in the system per customer

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{24}{30(30 - 24)}$$

$= 0.133$ hour (8 minutes) average time in the waiting line per customer

$$\rho = \frac{\lambda}{\mu} = \frac{24}{30}$$

$= 0.80$ probability that the server will be busy and the customer must wait

$$I = 1 - \rho = 1 - 0.80$$

$= 0.20$ probability that the server will be idle and a customer can be served

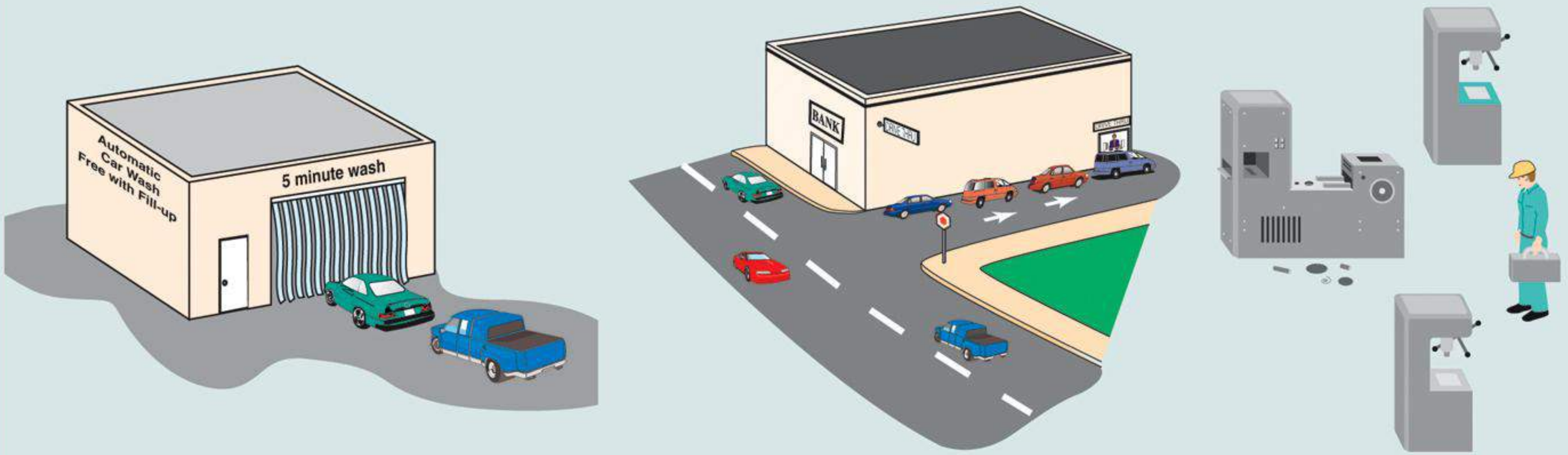
Service Improvement Analysis

- Waiting time (8 min.) is too long
  - hire assistant for cashier?
    - increased service rate
  - hire another cashier?
    - reduced arrival rate
- Is improved service worth the cost?

Advanced Single-Server Models

- Constant service times
  - occur most often when automated equipment or machinery performs service
- Finite queue lengths
  - occur when there is a physical limitation to length of waiting line
- Finite calling population
  - number of “customers” that can arrive is limited

Advanced Single-Server Models



(*a*) Single-Server, Constant Time

(*b*) Single-Server, Finite Queue

(*c*) Single-Server, Finite Calling Population

Basic Multiple-Server Model

- Single waiting line and service facility with several independent servers in parallel
- Same assumptions as single-server model
- $s\mu > \lambda$
  - s = number of servers
  - servers must be able to serve customers faster than they arrive

Basic Multiple-Server Model

- probability that there are no customers in system

$$P_0 = \frac{1}{\left[\displaystyle\sum_{n=0}^{n=s-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s\left(\frac{s\mu}{s\mu - \lambda}\right)}$$

- probability of n customers in system

$$P_n = \begin{cases} \dfrac{1}{s!s^{n-s}}\left(\dfrac{\lambda}{\mu}\right)^n P_0, & \text{for } n > s \\[2ex] \dfrac{1}{n!}\left(\dfrac{\lambda}{\mu}\right)^n P_0, & \text{for } n \le s \end{cases}$$

Basic Multiple-Server Model

- probability that customer must wait

$$P_w = \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \frac{s\mu}{s\mu - \lambda} P_0$$

$$L_q = L - \frac{\lambda}{\mu}$$

$$L = \frac{\lambda\mu\,(\lambda/\mu)^s}{(s-1)!\,(s\mu - \lambda)^2} P_0 + \frac{\lambda}{\mu}$$

$$W_q = W - \frac{1}{\mu} = \frac{L_q}{\lambda}$$

$$W = \frac{L}{\lambda}$$

$$\rho = \frac{\lambda}{s\mu}$$

Operating Characteristics

- *Operating characteristics* are assumed to approach a *steady state*

Notation	Operating Characteristic
L	Average number of customers in the system (waiting and being served)
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P_0	Probability of no (i.e., zero) customers in the system
P_n	Probability of *n* customers in the system
ρ	Utilization rate; the proportion of time the system is in use

Basic Multiple-Server Model Example

Three-server system

λ =10/hr

μ = 4/hr

S = *3*

*s*μ = 3 x 4 = 12

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=s-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s\left(\frac{s\mu}{s\mu - \lambda}\right)}$$

$$= \frac{1}{\left[\frac{0}{0!}\left(\frac{10}{4}\right)^0 + \frac{1}{1!}\left(\frac{10}{4}\right)^1 + \frac{1}{2!}\left(\frac{10}{4}\right)^2\right] + \frac{1}{3!}\left(\frac{10}{4}\right)^3 \frac{3(4)}{3(4) - 10}}$$

$=$ 0.045 probability that no customers are in the health service.

Basic Multiple-Server Model Example

$$L = \frac{\lambda\mu(\lambda/\mu)^s}{(s-1)!(s\mu-\lambda)^2}P_0 + \frac{\lambda}{\mu}$$

$$= \frac{(10)(4)(10/4)^3}{(3-1)![3(4)-10]^2}(0.045) + \frac{10}{4}$$

$= 6$ students in the health service

$$W = \frac{L}{\lambda}$$

$$= \frac{6}{10}$$

$= 0.60$ hour or 36 minutes in the health service

$$L_q = L - \frac{\lambda}{\mu}$$

$$= 6 - \frac{10}{4}$$

$= 3.5$ students waiting to be served

$$W_q = \frac{L_q}{\lambda}$$

$$= \frac{3.5}{10}$$

$= 0.35$ hour or 21 minutes waiting in line

Basic Multiple-Server Model Example

$$P_w = \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \frac{s\mu}{s\mu - \lambda} P_0$$

$$= \frac{1}{3!}\left(\frac{10}{4}\right)^3 \frac{3(4)}{3(4) - (10)}(0.045)$$

= 0.703 probability that a student must wait for service (i.e., that there are three or more students in the system)

Basic Multiple-Server Model Example

- To cut waiting time, add another service rep
- Four-server System

P_0 = 0.073 probability that no students are in the health service
L = 3.0 students in the health service
W = 0.30 hour, or 18 minutes, in the health service
L_q = 0.5 students waiting to be served
W_q = 0.05 hour, or 3 minutes, waiting in line
P_w = 0.31 probability that a student must wait for service

Processes and Technology

Lecture Outline

- Process Planning
- Process Analysis
- Process Innovation
- Amortization
- Technology Decisions

Learning Objectives

- Evaluate strategic options in process planning, including whether or not to outsource
- Differentiate among different types of production processes
- Understand the effect of volume and standardization on process selection
- Appreciate the difficulties in translating a design to a process
- Use simple flowcharting tools to improve everyday processes
- Investigate the use of technology in manufacturing and service processes

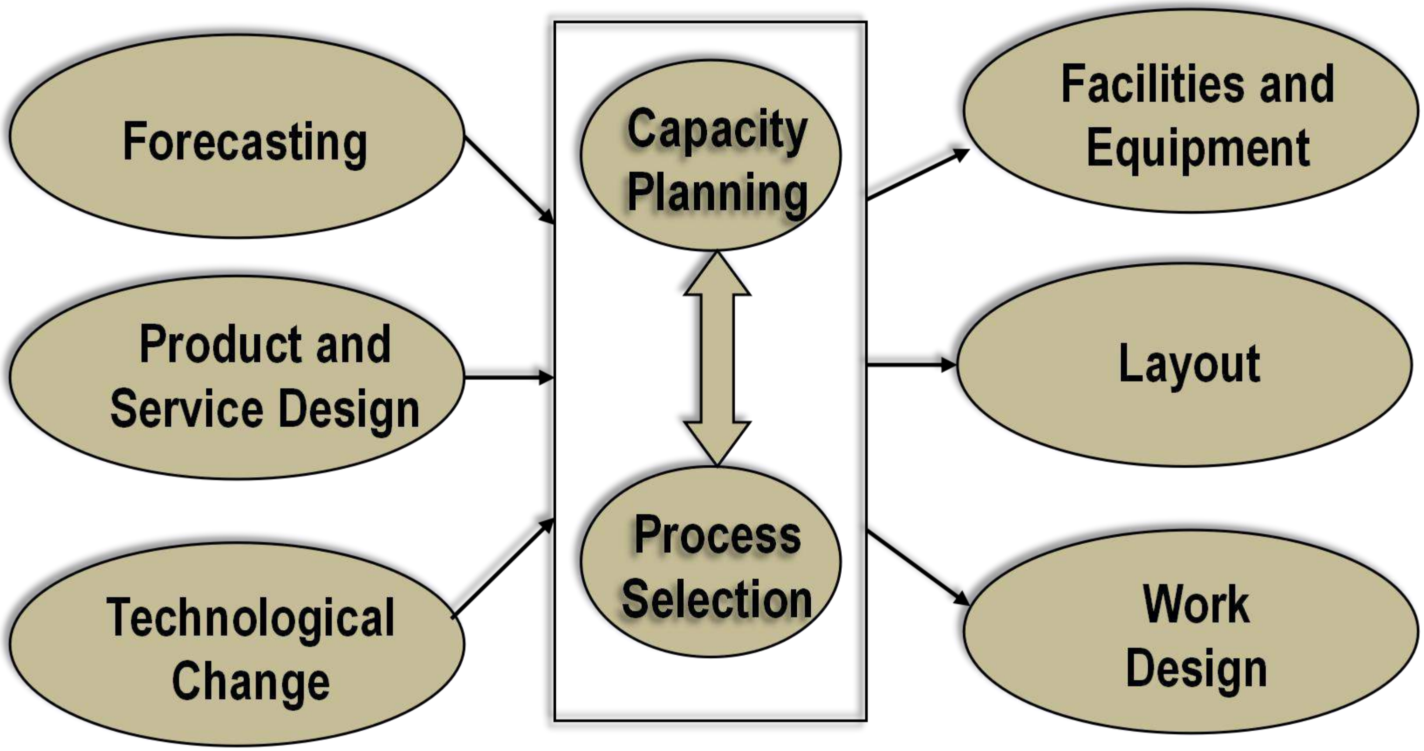
Process Planning

- Process
  - Group of related tasks with specific inputs & outputs
- Process design
  - tasks to be done & how they are coordinated among functions, people, & organizations
- Process strategy
  - an organization’s overall approach for physically producing goods and services
- Process planning
  - converts designs into workable instructions for manufacture or delivery

Process Selection

- Process selection
  - Refers to deciding on the way production of goods or services will be organized
  - It has major implications for
    - Capacity planning
    - Layout of facilities
    - Equipment
    - Design of work systems

Process Selection and System Design



Process Strategy

- Vertical integration
  - extent to which firm will produce inputs and control outputs of each stage of production process
- Capital intensity
  - mix of capital (i.e., equipment, automation) and labor resources used in production process
- Process flexibility
  - ease with which resources can be adjusted in response to changes in demand, technology, products or services, and resource availability
- Customer involvement
  - role of customer in production process

Outsourcing

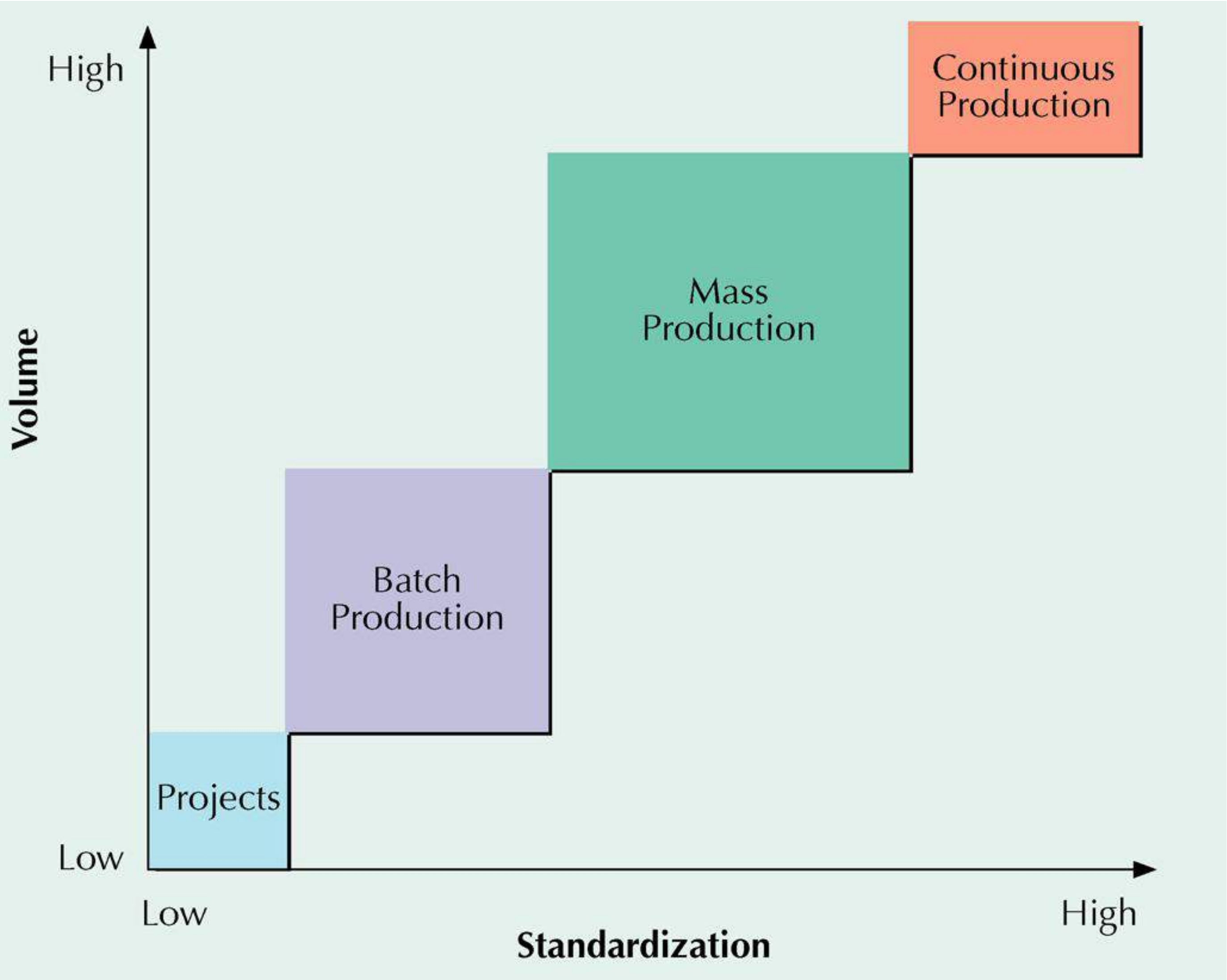
- Cost
  - Is it cheaper to make or buy the item
- Capacity
  - Does the company have the capacity
- Quality
  - Easier to control quality in your own factory
- Speed
  - Shipping time can reduce savings
- Reliability
  - Quality and timing are reliability measures
- Expertise
  - Protect proprietary information

Sourcing Continuum

Process Selection

- Projects
  - one-of-a-kind production of a product to customer order
- Batch production
  - process many different jobs at the same time in groups or batches
- Mass production
  - produce large volumes of a standard product for a mass market
- Continuous production
  - used for very-high volume commodity products

Product-Process Matrix



Types of Processes

	PROJECT	BATCH	MASS	CONT.
Type of product	Unique	Made-to-order (customized)	Made-to-stock (standardized)	Commodity
Type of customer	One-at-a-time	Few individual customers	Mass market	Mass market
Product demand	Infrequent	Fluctuates	Stable	Very stable

Types of Processes

	PROJECT	BATCH	MASS	CONT.
Demand volume	Very low	Low to medium	High	Very high
No. of different products	Infinite variety	Many, varied	Few	Very few
Production system	Long-term project	Discrete, job shops	Repetitive, assembly lines	Continuous, process industries

Types of Processes

	PROJECT	BATCH	MASS	CONT.
Equipment	Varied	General-purpose	Special-purpose	Highly automated
Primary type of work	Specialized contracts	Fabrication	Assembly	Mixing, treating, refining
Worker skills	Experts, crafts-persons	Wide range of skills	Limited range of skills	Equipment monitors

Types of Processes

	PROJECT	BATCH	MASS	CONT.
Advantages	Custom work, latest technology	Flexibility, quality	Efficiency, speed, low cost	Highly efficient, large capacity, ease of control
Dis-advantages	Non-repetitive, small customer base, expensive	Costly, slow, difficult to manage	Capital investment; lack of responsiveness	Difficult to change, far-reaching errors, limited variety
Examples	Construction, shipbuilding, spacecraft	Machine shops, print shops, bakeries, education	Automobiles, televisions, computers, fast food	Paint, chemicals, foodstuffs

Process Selection With Break-Even Analysis

- Study cost trade-offs based on demand volume
- Cost
  - Fixed costs
    - constant regardless of the number of units produced
  - Variable costs
    - vary with the volume of units produced
- Revenue
  - price at which an item is sold

Process Selection With Break-Even Analysis

- Total revenue
  - price times volume sold
- Profit
  - difference between total revenue and total cost

Process Selection With Break-Even Analysis

Total cost = fixed cost + total variable cost

$TC = c_f + vc_v$

Total revenue = volume x price

$TR = vp$

Profit = total revenue - total cost

$Z = TR – TC = vp - (c_f + vc_v)$

c_f = fixed cost

V = volume (i.e., number of units produced and sold)

c_v = variable cost per unit

p = price per unit

Process Selection With Break-Even Analysis

TR = TC

$$vp = c_f + vc_v$$

$$vp - vc_v = c_f$$

$$v(p - c_v) = c_f$$

$$v = \frac{c_f}{p - c_v}$$

Solving for Break-Even Point (Volume)

Break-Even Analysis

Fixed cost = c_f = \$2,000
Variable cost = c_v = \$50 per unit
Price = p = \$100 per unit

Break-even point is

$$v = \frac{c_f}{p - c_v} =$$

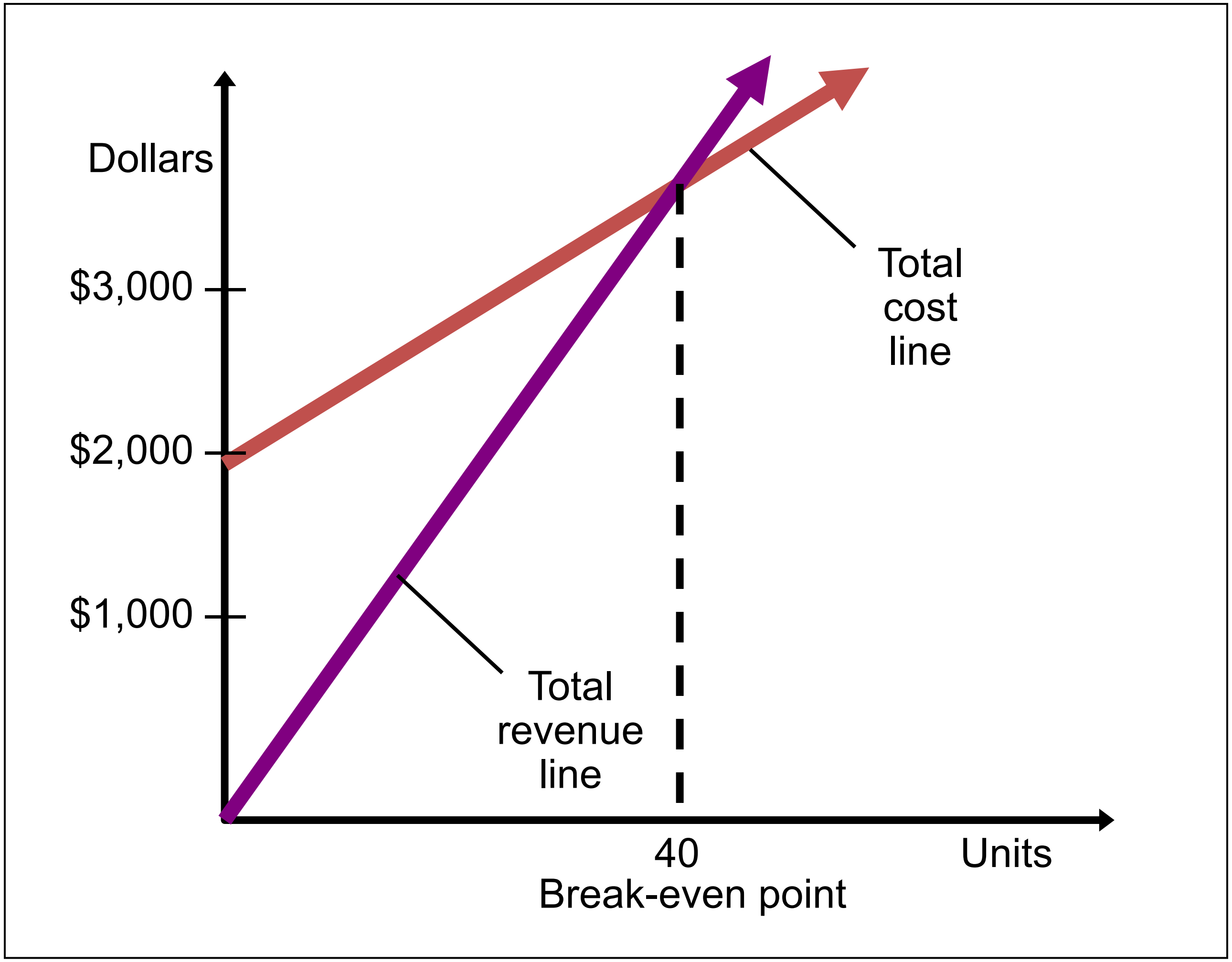
Break-Even Analysis

Fixed cost = c_f = \$2,000
Variable cost = c_v = \$50 per unit
Price = p = \$100 per unit

Break-even point is

$$v = \frac{c_f}{p - c_v} = \frac{2000}{100 - 50} = 40 \text{ units}$$

Break-Even Analysis: Graph



Process Selection – Multiple Processes

Process A *Process B*

$$\$2{,}000 + \$50v = \$10{,}000 + \$30v$$

Process Selection – Multiple Processes

Process A *Process B*

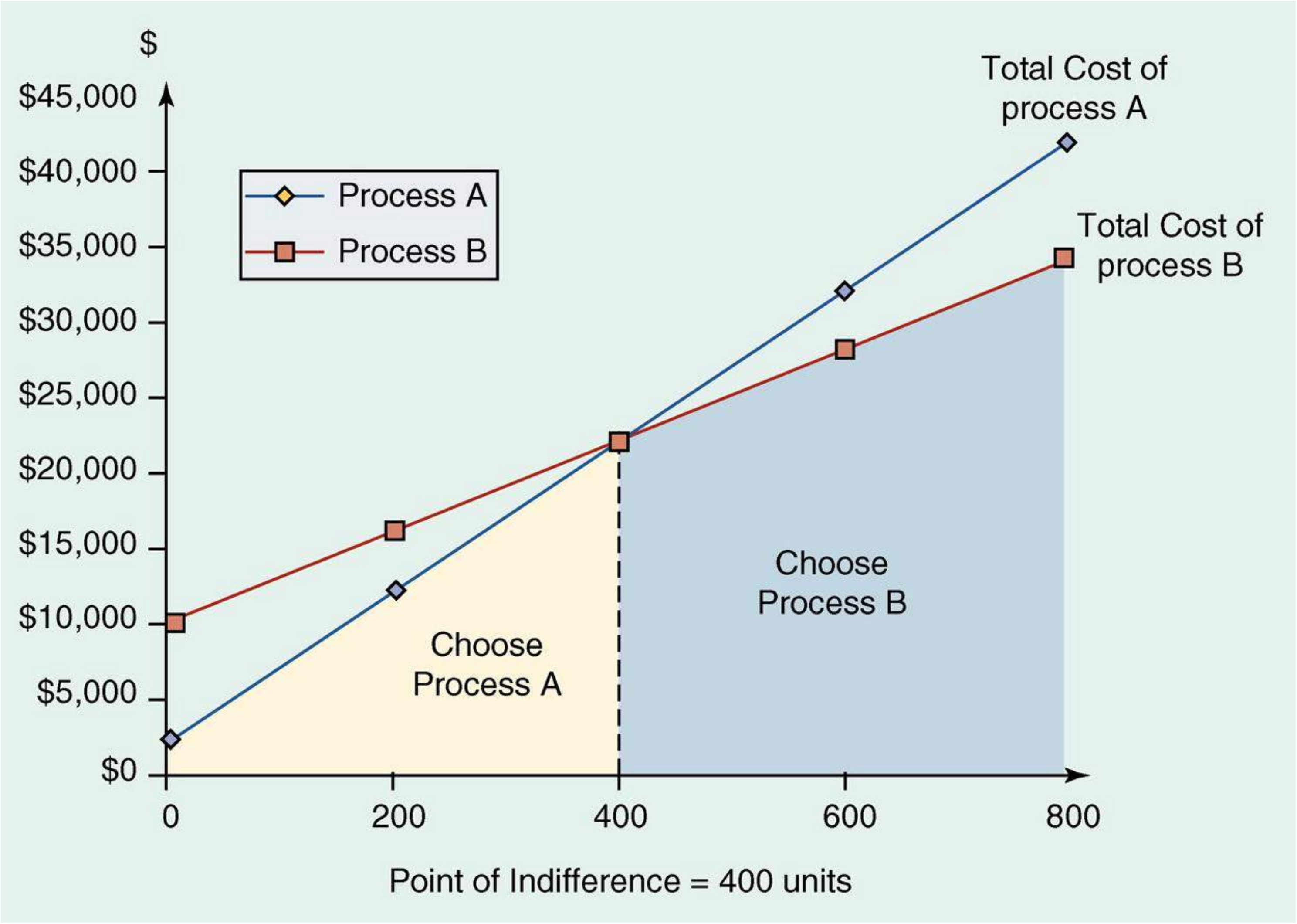
$$\$2{,}000 + \$50v = \$10{,}000 + \$30v$$

$$\$20v = \$8{,}000$$

$$v = 400 \text{ units}$$

Below or equal to 400, choose A
Above or equal to 400, choose B

Multiple Processes – Indifference Point



Capital equipment (Furnace A)

Cost = 100,000

R = 12%

Lifetime = 20 years

Annualized amount = ?

Capital equipment (Furnace B)

Cost = 120,000

R = 12%

Lifetime = 30 years

Annualized amount = ?

Ammortization/Annualization

$$S_n = a + ar + ar^2 + ar^3 + \ldots ar^{n-1}$$

$$S_n = a(1 - r^n)/(1 - r)$$

$P = Principal$

R = Annual interest rate

N = Time duration/number of intervals

SI = Simple interest

$$SI = P * R * N$$

$$A_1 = P(1 + R)$$

$$A_n = P(1 + R)^N$$

Amortization/Annualization

$Y = Amount\ loaned$

X = Annual Instalment

N = Time duration/lifetime

R = Rate of interest

$$\mathrm{X}(1+R)^{N} + \mathrm{X}(1+R)^{N-1} + \dots + \mathrm{X}(1+R) = \mathrm{Y}(1+R)^{N}$$

$$\mathrm{X}\{(1+R)^{N} + (1+R)^{N-1} + \dots + (1+R)\} = \mathrm{Y}(1+R)^{N}$$

$$\mathrm{X}\{1-(1+R)^{N} \,/\, (1 - (1+R)\} = \mathrm{Y}(1+R)^{N}$$

$$\mathrm{X} = \mathrm{Y} * \mathrm{R} * (1+R)^{N}/((1+R)^{N} - 1)$$

Capital equipment (Furnace A)
Cost = 100,000
R = 12%
Lifetime = 20 years
Annualized amount = ?

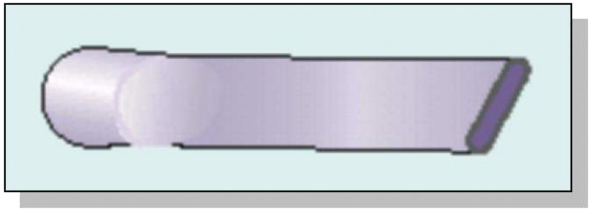
Capital equipment (Furnace B)
Cost = 120,000
R = 12%
Lifetime = 30 years
Annualized amount = ?

Process Plans

- Set of documents that detail manufacturing and service delivery specifications
  - assembly charts
  - operations sheets
  - quality-control check-sheets

Operations Sheet for Plastic Part

Part name	Crevice Tool
Part No.	52074
Usage	Hand-Vac
Assembly No.	520



Oper. No.	*Description*	*Dept.*	*Machine/Tools*	*Time*
10	Pour in plastic bits	041	Injection molding	2 min
20	Insert mold	041	#076	2 min
30	Check settings & start machine	041	113, 67, 650	20 min
40	Collect parts & lay flat	051	Plastics finishing	10 min
50	Remove & clean mold	042	Parts washer	15 min
60	Break off rough edges	051	Plastics finishing	10 min

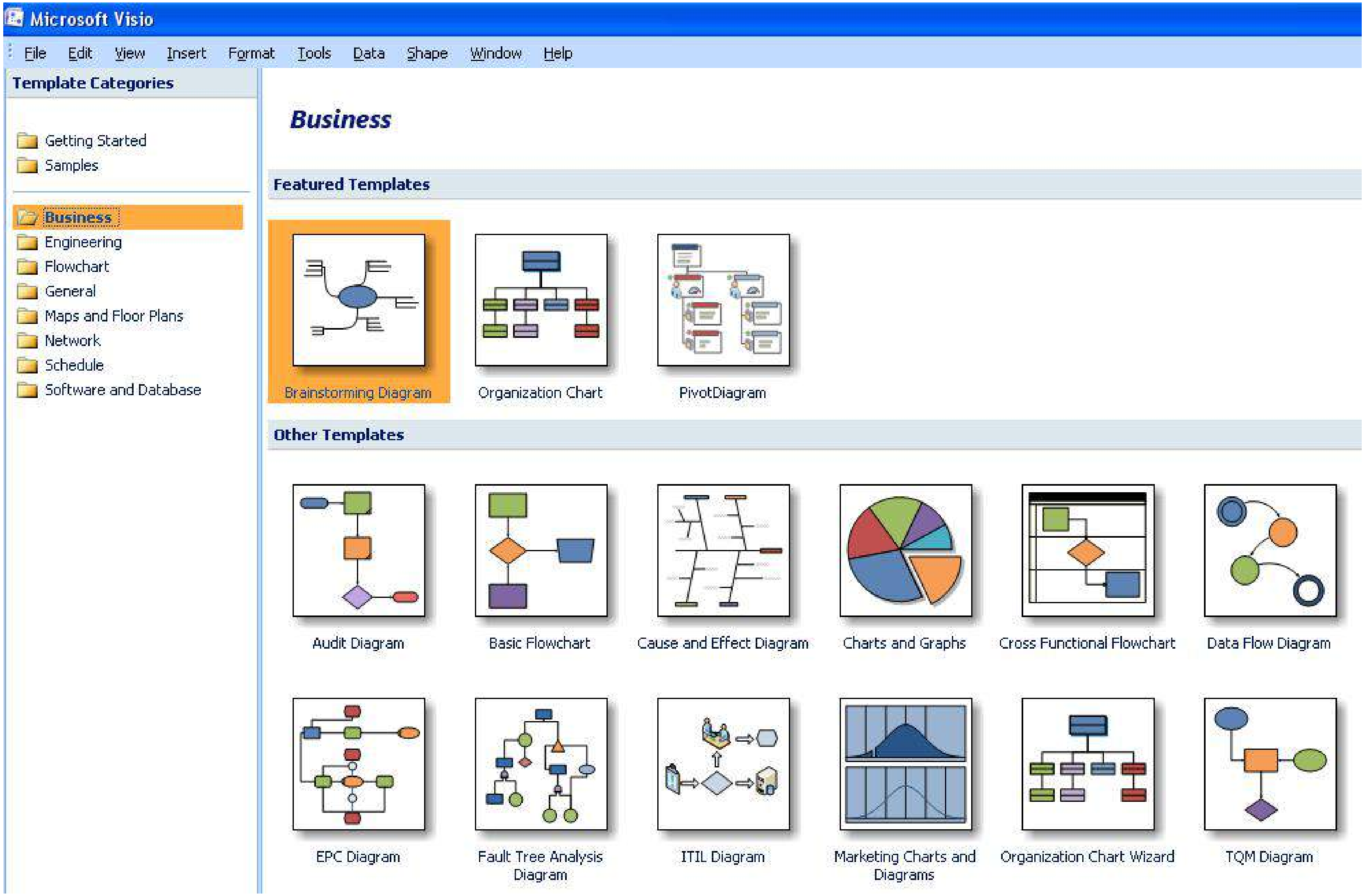
Process Analysis

- Systematic study of all aspects of a process
  - make it faster
  - more efficient
  - less costly
  - more responsive
- Basic tools
  - process flowcharts
  - diagrams
  - maps

Building a Flowchart

- Determine objectives
- Define process boundaries
- Define units of flow
- Choose type of chart
- Observe process and collect data
- Map out process
- Validate chart

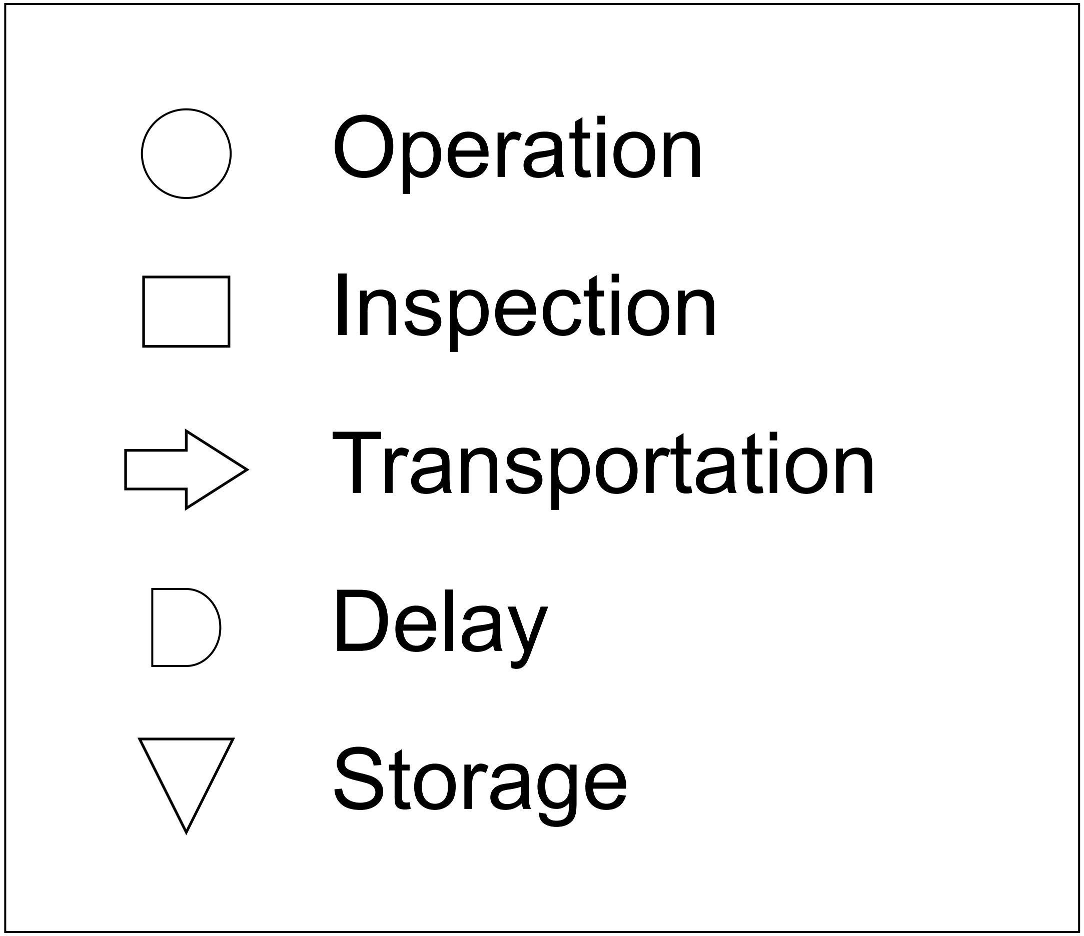
Flow Charts in Microsoft Visio



Process Flowcharts

- Look at manufacture of product or delivery of service from broad perspective
- Incorporate
  - nonproductive activities (inspection, transportation, delay, storage)
  - productive activities (operations)

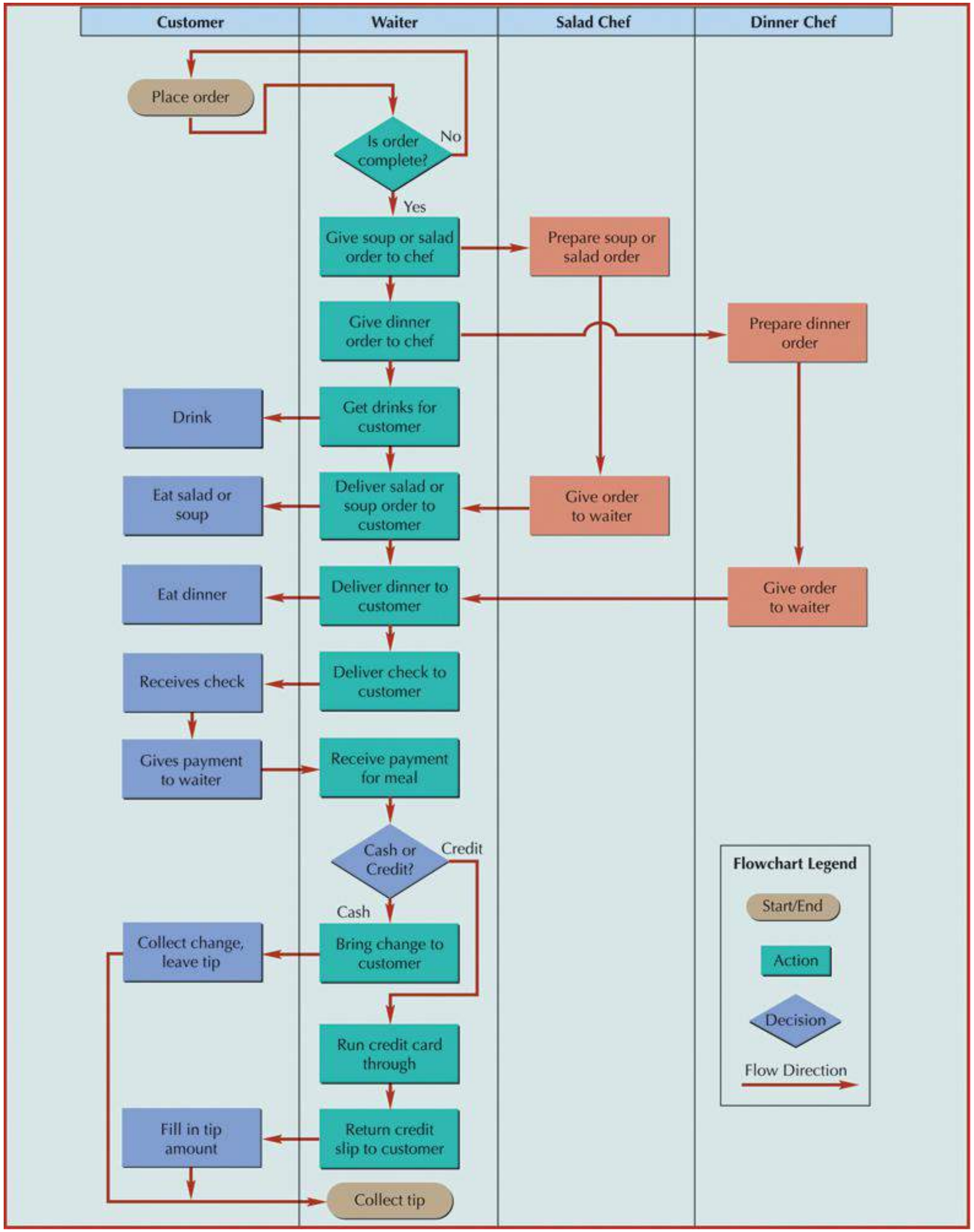
Process Flowchart Symbols



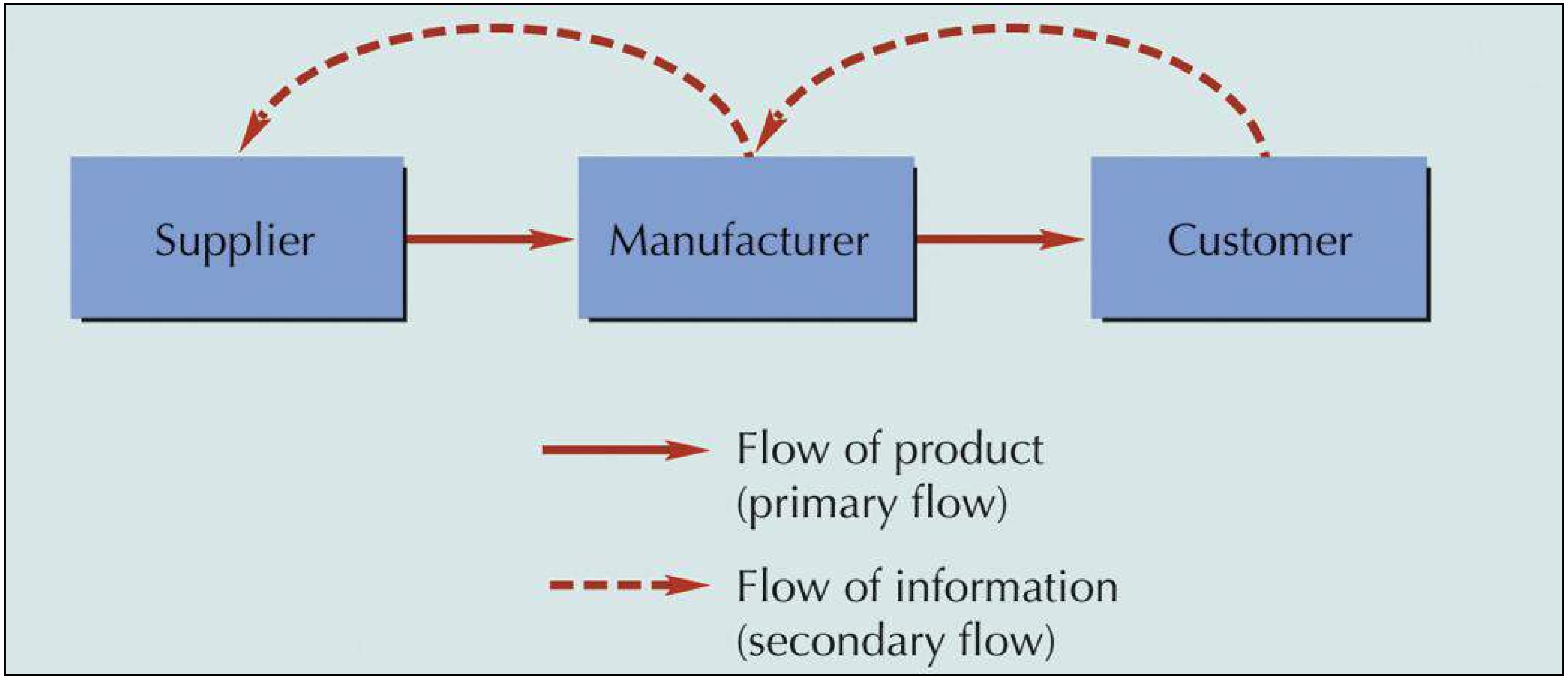
Process Flowchart of Apple Processing

Date: 9-30-12						Location: Graves Mountain		
Analyst: TLR						Process: Applesauce		
Step	Operation	Transport	Inspect	Delay	Storage	Description of process	Time (min)	Distance (feet)
1	●	⇨	□	D	▽	Unload apples from truck	20	
2	○	➡	□	D	▽	Move to inspection station		100 ft
3	○	⇨	■	D	▽	Weigh, inspect, sort	30	
4	○	➡	□	D	▽	Move to storage		50 ft
5	○	⇨	□	D	▼	Wait until needed	360	
6	○	➡	□	D	▽	Move to peeler		20 ft
7	●	⇨	□	D	▽	Peel and core apples	15	
8	○	⇨	□	D	▼	Soak in water until needed	20	
9	●	⇨	□	D	▽	Place on conveyor	5	
10	○	➡	□	D	▽	Move to mixing area		20 ft
	Page 1 of 3					Total	450	190 ft

Process Map or Swimlane Chart of Restaurant Service

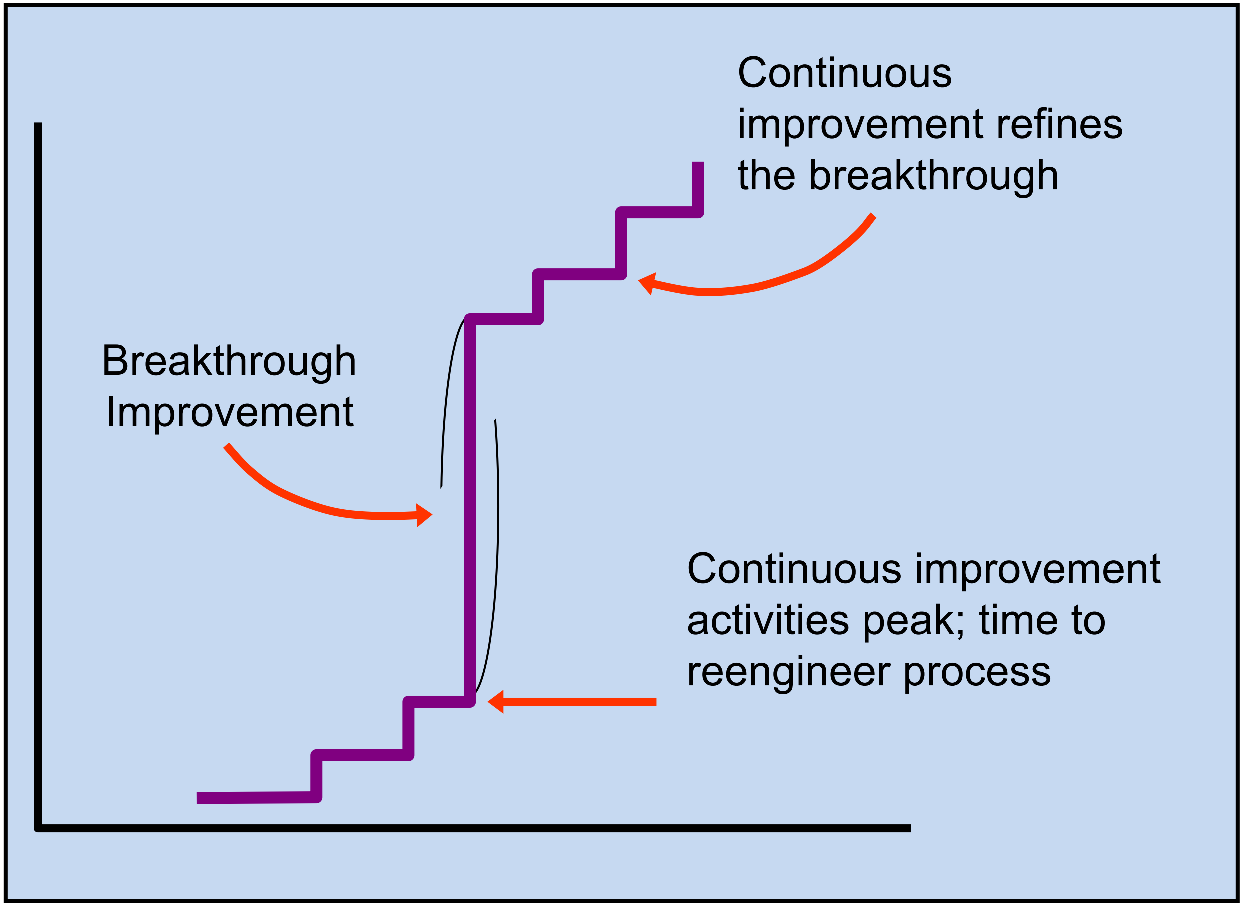


Simple Value Chain Flowchart

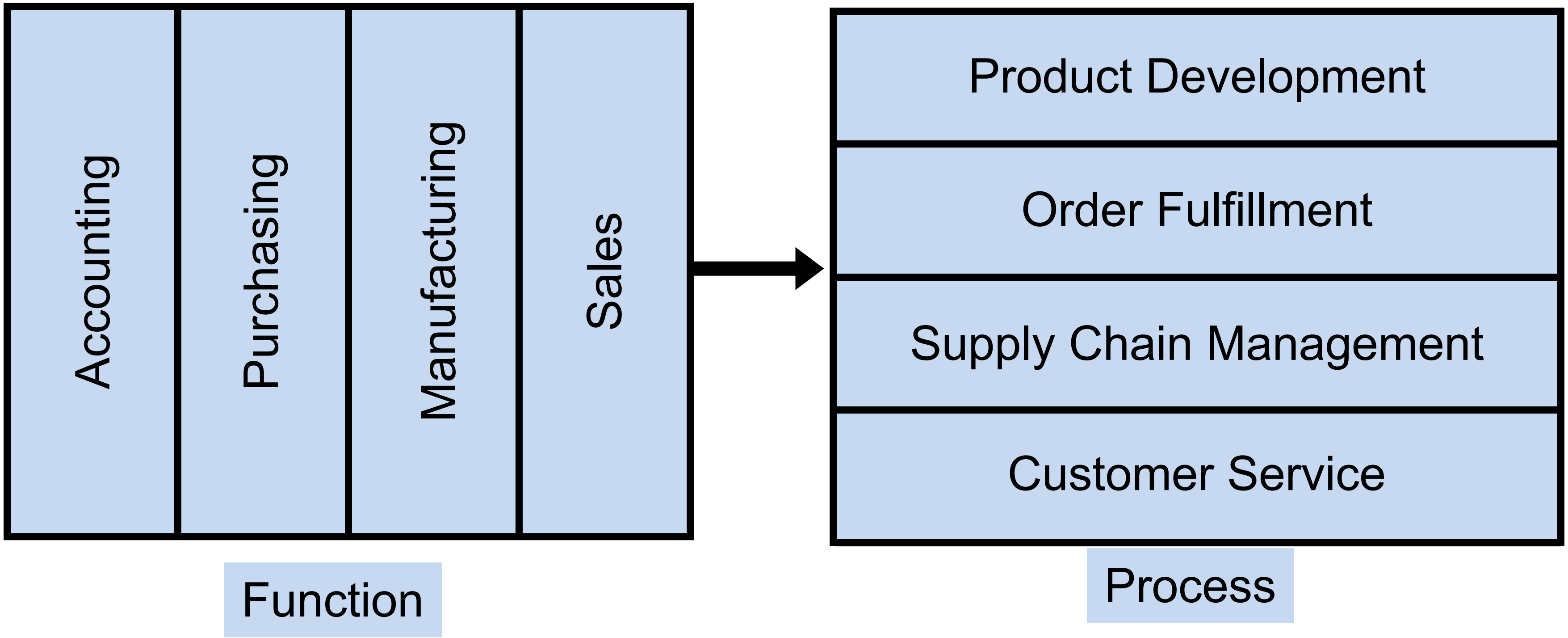


Process Innovation

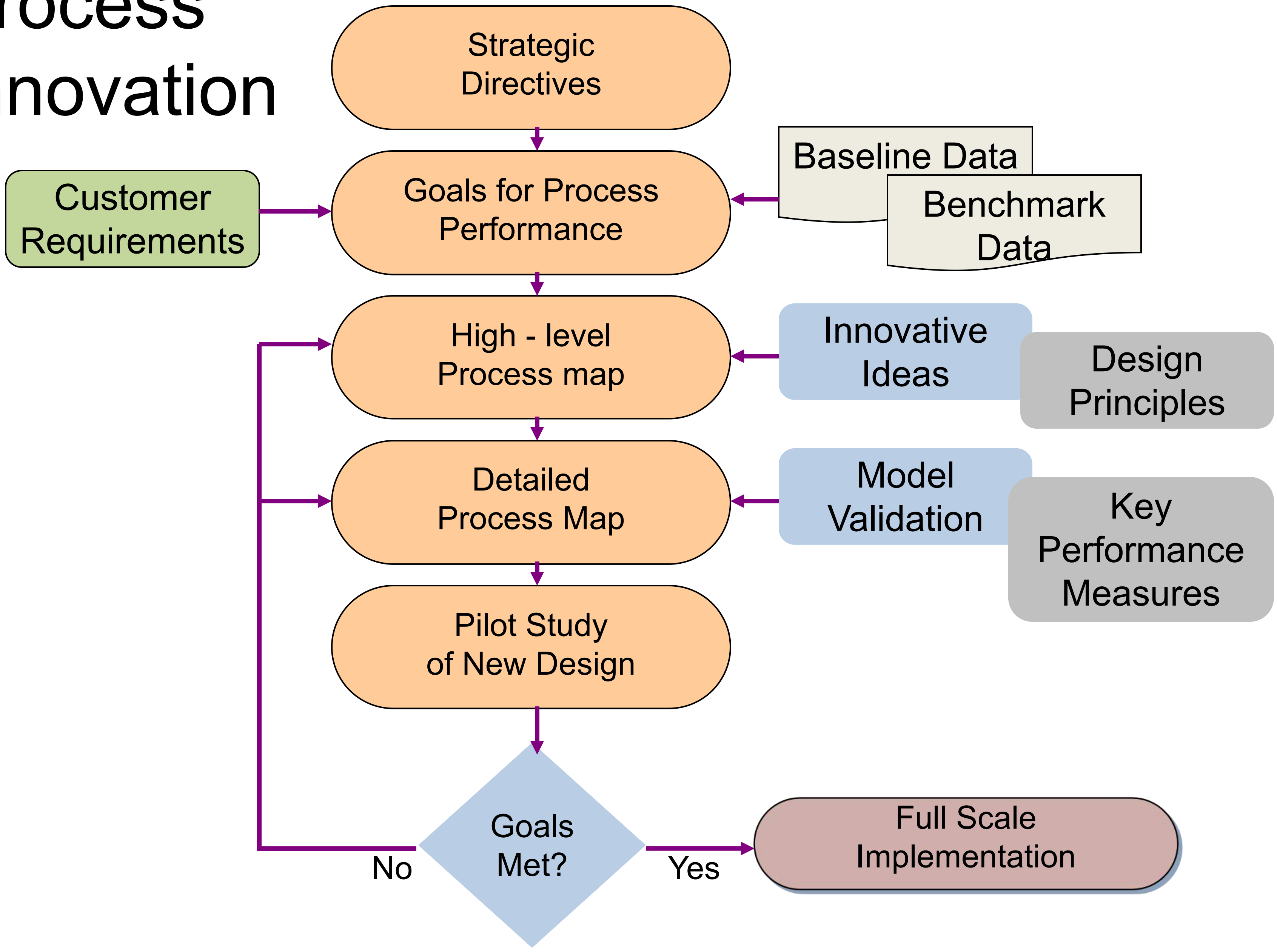
Total redesign of a process for breakthrough improvements



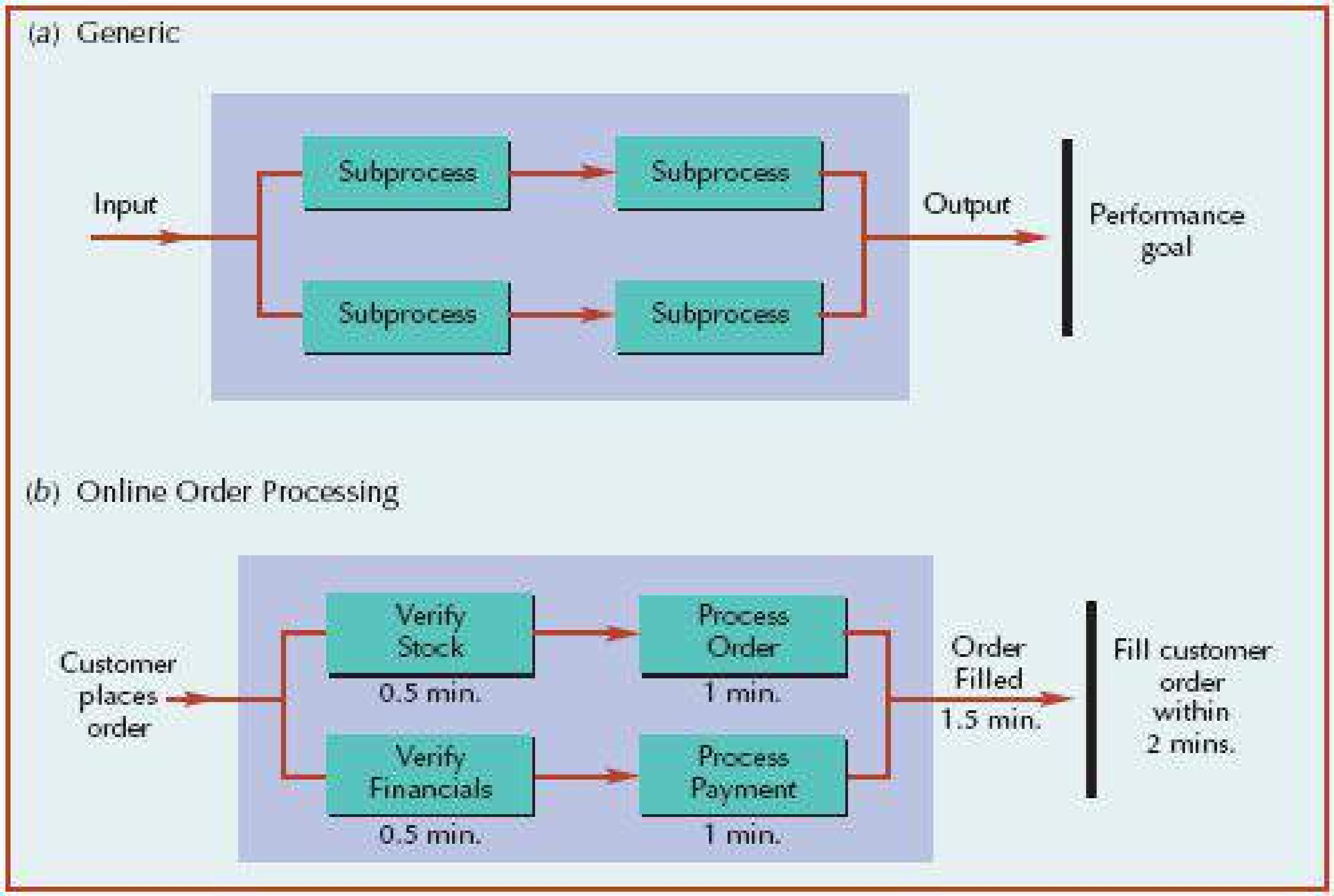
From Function to Process



Process Innovation



High-Level Process Map



Principles for Redesigning Processes

- Remove waste, simplify, and consolidate similar activities
- Link processes to create value
- Let the swiftest and most capable enterprise execute the process
- Flex process for any time, any place, any way
- Capture information digitally at the source and propagate it through process

Principles for Redesigning Processes

- Provide visibility through fresher and richer information about process status
- Fit process with sensors and feedback loops that can prompt action
- Add analytic capabilities to the process
- Connect, collect, and create knowledge around process through all who touch it
- Personalize process with preferences and habits of participants

Techniques for Generating Innovative Ideas

- Vary the entry point to a problem
  - in trying to untangle fishing lines, it’s best to start from the fish, not the poles
- Draw analogies
  - a previous solution to an old problem might work
- Change your perspective
  - think like a customer
  - bring in persons who have no knowledge of process

Techniques for Generating Innovative Ideas

- Try inverse brainstorming
  - what would *increase* cost
  - what would *displease* the customer
- Chain forward as far as possible
  - if I solve this problem, what is the next problem
- Use attribute brainstorming
  - how would this process operate if. . .
    - our workers were mobile and flexible
    - there were no monetary constraints
    - we had perfect knowledge

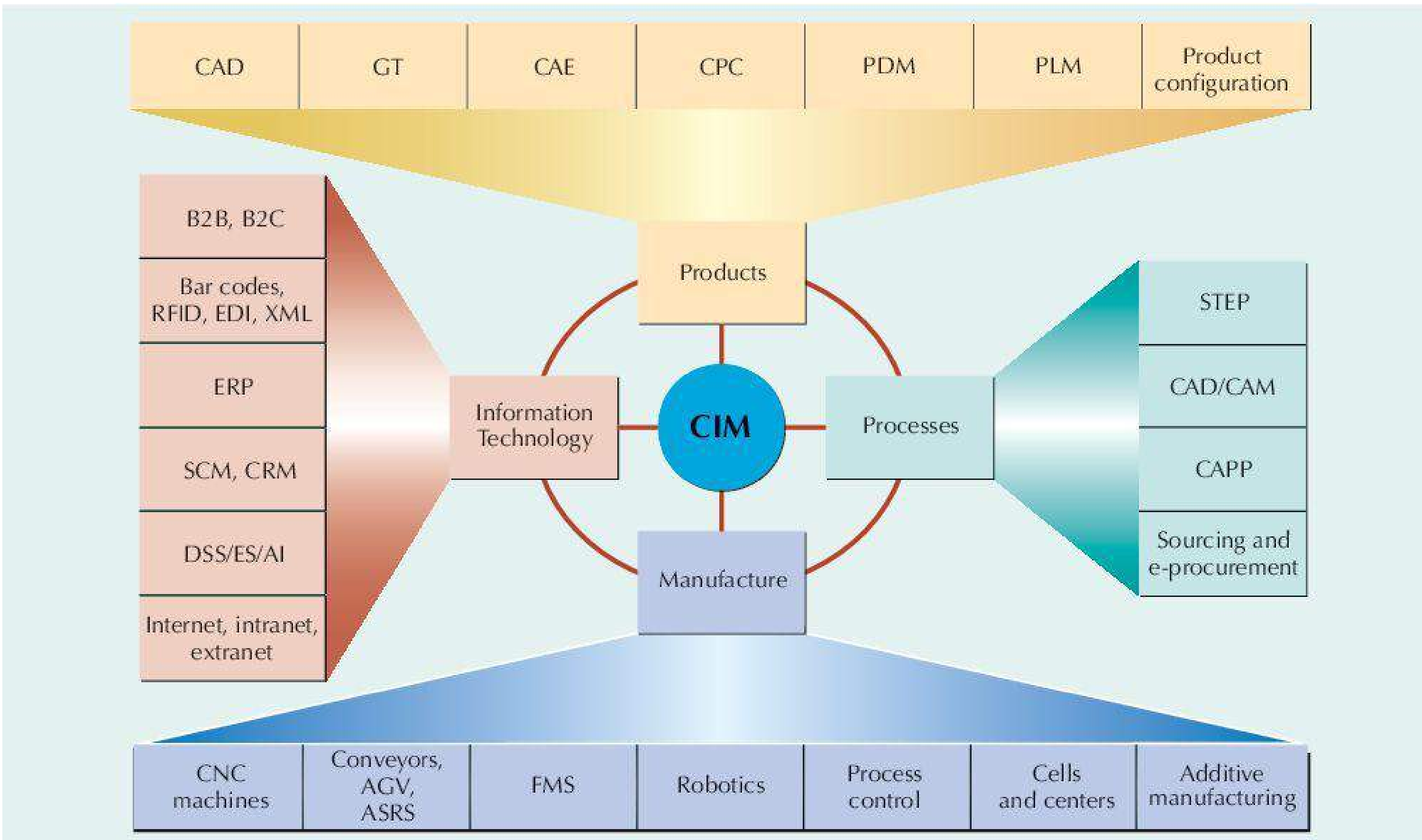
Financial Justification of Technology

- Purchase cost
  - Includes add-ons to make technology work
- Operating Costs
  - Visualize how the technology will be used
- Annual Savings
  - Better quality and efficiency save money
- Revenue Enhancement
  - New technology can enhance revenue

Financial Justification of Technology

- Replacement Analysis
  - When to upgrade to new technology depends on competitive environment
- Risk and Uncertainty
  - It is risky to invest and risky to
- Piecemeal Analysis
  - Make sure new and existing technology are compatible

Advanced Components of Manufacturing



Product Technology

- Computer-aided design (CAD)
  - Creates and communicates designs electronically
- Group technology (GT)
  - Classifies designs into families for easy retrieval and modification
- Computer-aided engineering (CAE)
  - Tests functionality of CAD designs electronically
- Collaborative product commerce (CPC)
  - Facilitates electronic communication and exchange of information among designers and suppliers

Product Technology

- Product data management (PDM)
  - Keeps track of design specs and revisions for the life of the product
- Product life cycle management (PLM)
  - Integrates decisions of those involved in product development, manufacturing, sales, customer service, recycling, and disposal
- Product configuration
  - Defines products “configured” by customers who have selected among various options, usually from a Web site

Process Technology

- Standard for exchange of product model data (STEP)
  - Set standards for communication among different CAD vendors; translates CAD data into requirements for automated inspection and manufacture
- Computer-aided design and manufacture (CAD/CAM)
  - Electronic link between automated design (CAD) and automated manufacture (CAM)
- Computer aided process (CAPP)
  - Generates process plans based on database of similar requirements
- E-procurement
  - Electronic purchasing of items from e-marketplaces, auctions, or company websites

Manufacturing Technology - 1

- Computer numerically control (CNC)
  - Machines controlled by software to perform a range of operations with the help of automated tool changers; collects processing information and quality data
- Flexible manufacturing system (FMS)
  - A collection of CNC machines connected by an automated material handling system to produce a wide variety of parts
- Robots
  - Programmable manipulators that can perform repetitive tasks; more consistent than workers but less flexible

Manufacturing Technology - 2

- Conveyors
  - Fixed-path material handling; move items along a belt or chain; “reads” package labels and diverts them to correct destination
- Automatic guided vehicle (AGV)
  - Driverless trucks that move material along a specified path; directed by wire or tape embedded in floor or by radio frequencies
- Automated storage and retrieval system (ASRS)
  - An automated warehouse; items placed in a storage system and retrieved by fast-moving stacker cranes; controlled by computer

Manufacturing Technology - 3

- Process Control
  - Continuous monitoring of automated equipment; makes real-time decisions on ongoing operation, maintenance, and quality
- Computer-integrated manufacturing (CIM)
  - Automated manufacturing systems integrated through computer technology; also called e-manufacturing
- Additive Manufacturing
  - Building up a product layer-by-layer from digital instructions, 3-D printing

Information Technology

- Business – to –Business (B2B)
  - E-transactions between businesses usually via the Internet
- Business – to –Consumer (B2C)
  - E-transactions between businesses and their customers usually via the Internet
- Internet
  - A global information system of computer networks that facilitates communication and data transfer
- Intranet
  - Communication networks internal to an organization; can also be password (i.e., firewall) protected sites on the Internet

Information Technology

- Extranet
  - Intranets connected to the Internet for shared access with select suppliers, customers, and trading partners
- Bar Codes
  - Series of vertical lines printed on packages that identify item and other information
- Radio Frequency Identification tags (RFID)
  - Integrated circuit embedded in a tag; can send and receive information; a "twenty-first century bar code" with read/write capabilities
- Electronic data interchange (EDI)
  - Computer-to-computer exchange of business documents over a proprietary network; very expensive and inflexible

Information Technology

- Extensible markup language (XML)
  - A markup language that facilitates computer–to–computer communication over the Internet by tagging data before its is sent
- Enterprise resource planning (ERP)
  - Software for managing key functions of an enterprise, including sales, marketing, finance, accounting, production, materials management & human resources
- Supply chain management (SCM)
  - Software to manage flow of goods and information among a network of suppliers, manufacturers and distributors
- Customer relationship management (CRM)
  - Software to manage interactions with customers; compiling and analyzing customer data

Information Technology

- Decision support systems (DSS)
  - Information system to help managers make decisions; includes quantitative modeling components and interactive components for what-if analysis
- Expert systems (ES)
  - A computer system that uses the knowledge of experts to diagnose or solve a problem
- Artificial intelligence (AI)
  - Field of study replicating elements of human thought and natural processes in software; includes expert systems, genetic algorithms, neural networks, and fuzzy logic