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

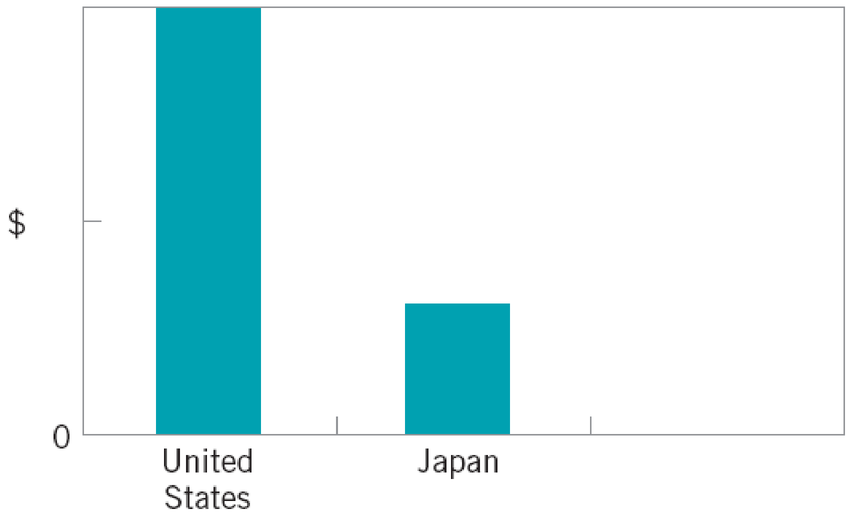


FIGURE 1.1 Warranty costs for transmissions.

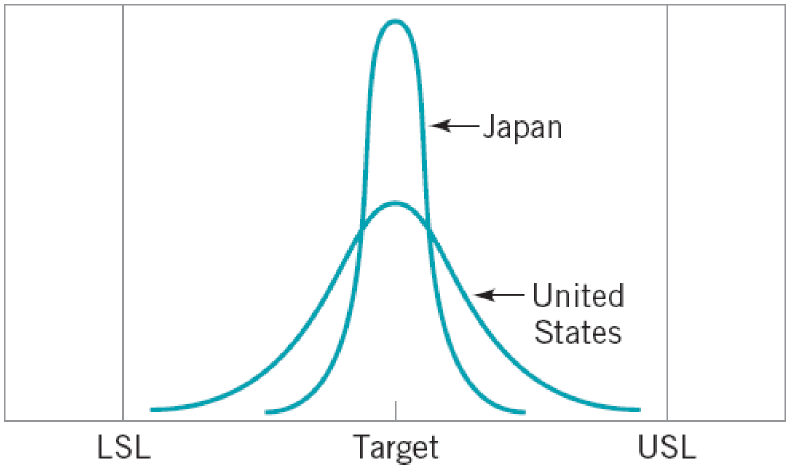


FIGURE 1.2 Distributions of critical dimensions for transmissions.

- 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

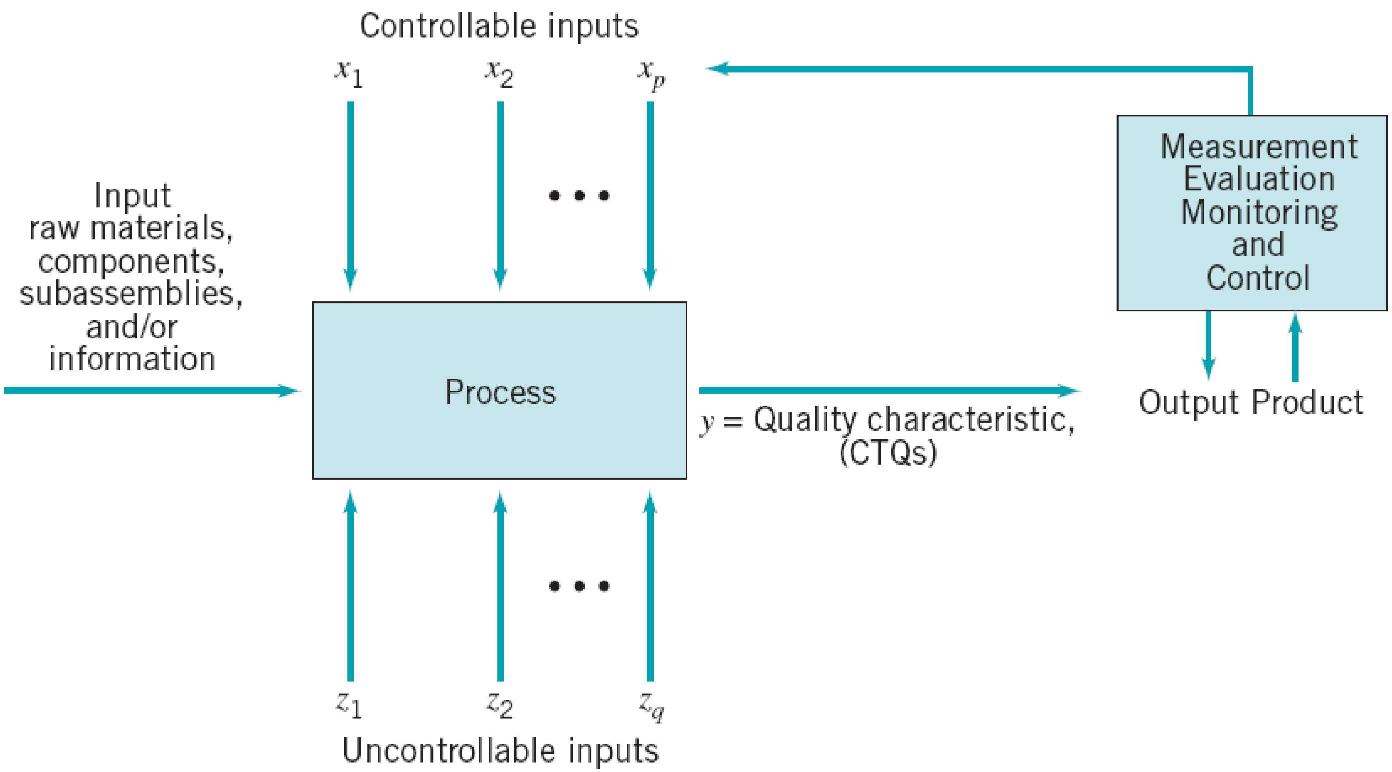


FIGURE 1.3 Production process inputs and outputs.

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)

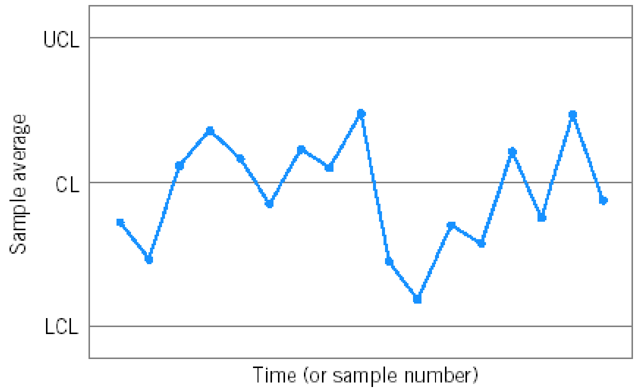
- Walter A. Shewart (1891-1967)
- Trained in engineering and physics
- Long career at Bell Labs
- 

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.

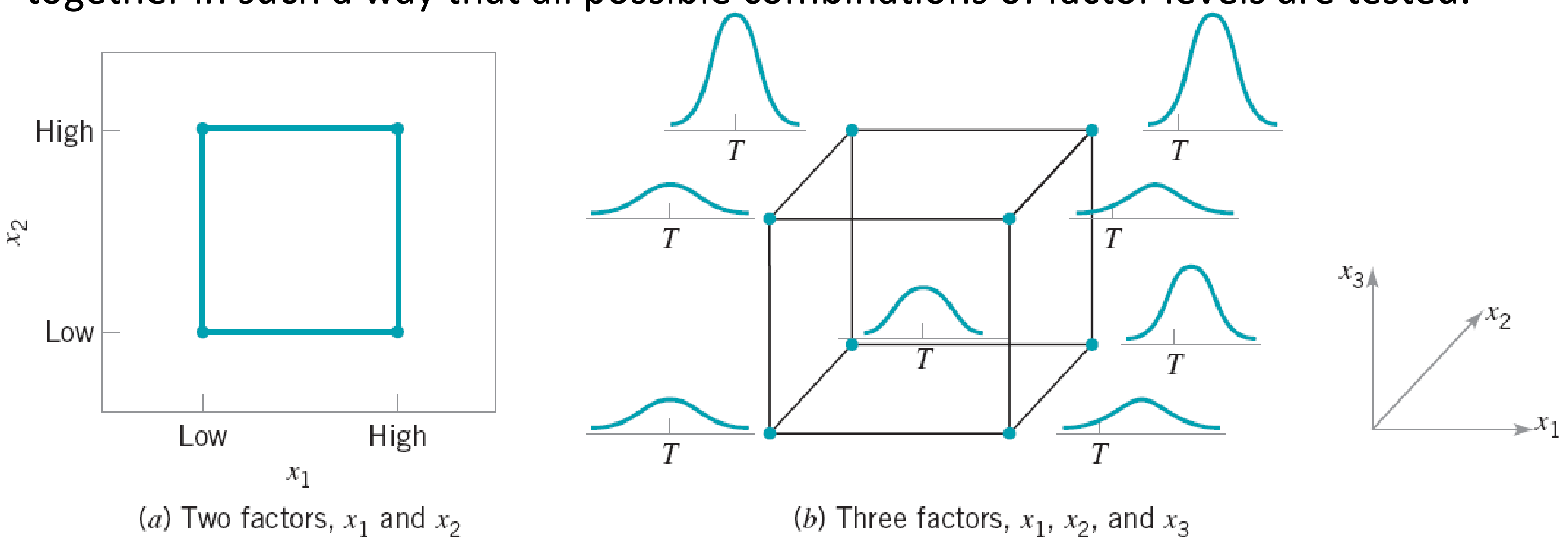


FIGURE 1.5 Factorial designs for the process in Fig. 1.3.

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.

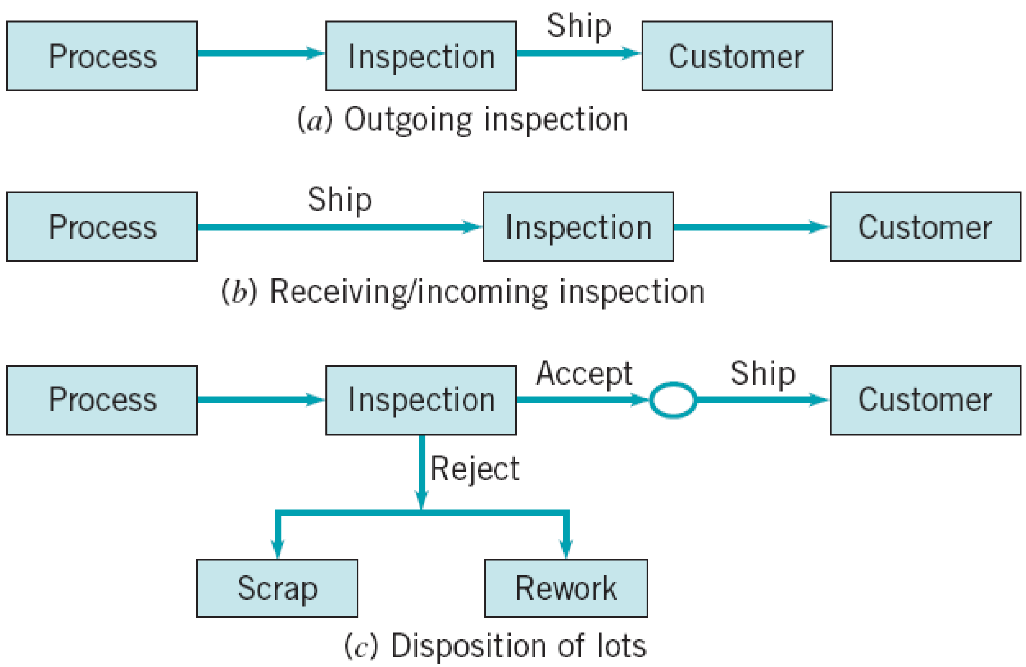


FIGURE 1.6 Variations of acceptance sampling.

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.

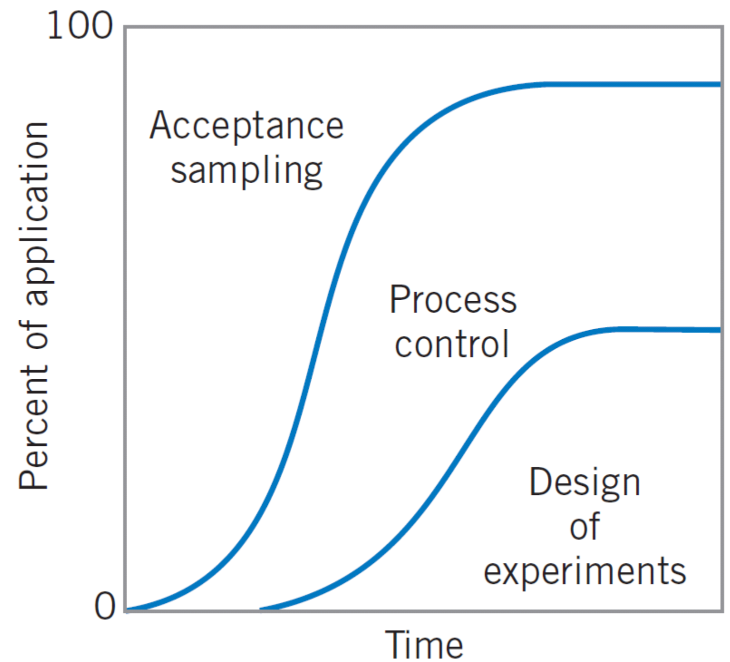


Figure 1.7 Phase Diagram of the Use of Quality-Engineering Methods

Quality Engineering

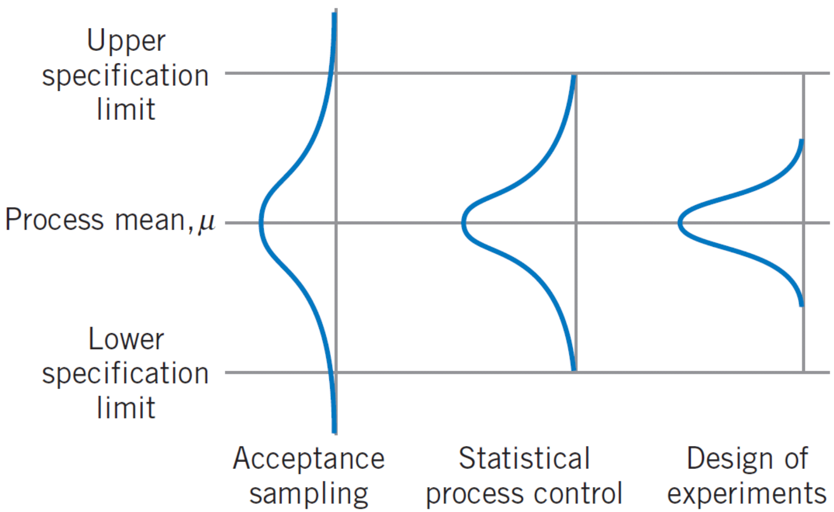


Figure 1.8 Application of Quality-Engineering Techniques and the Systematic Reduction of Process Variability

- 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.

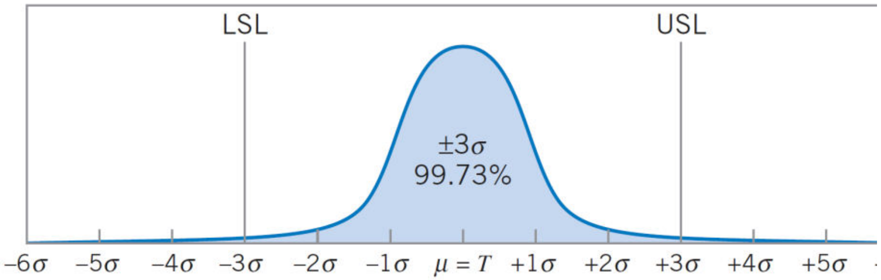
- The focus of six-sigma is reducing variability in key product quality characteristics to the level at which failure or defects are extremely unlikely.

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

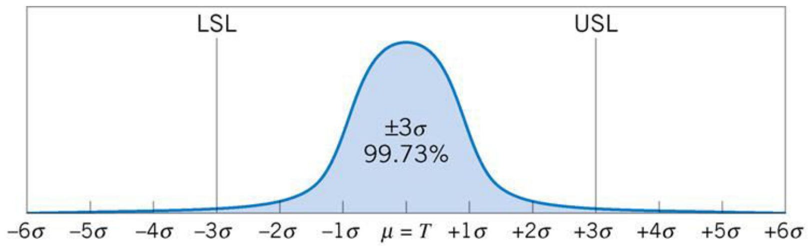
0.9973 * 0.9973 *. . .* 0.9973 = 0.7631

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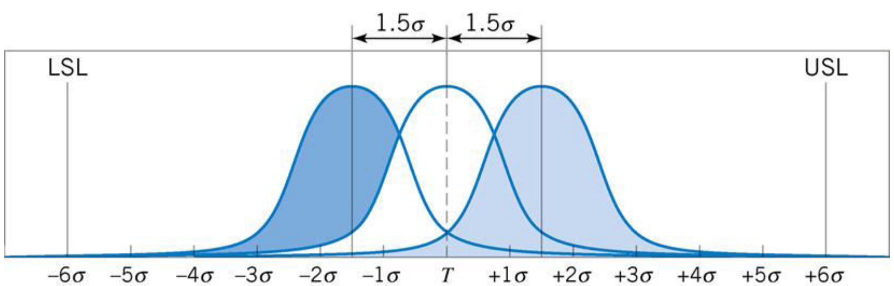
(a) Normal distribution centered at the target (*T*)



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!

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

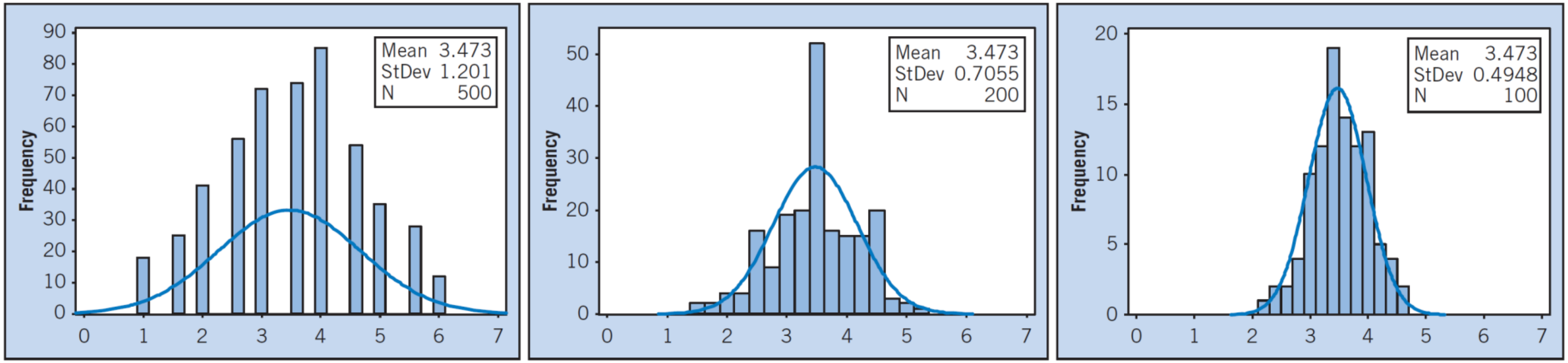


Figure 4.20 Distribution Created by Averaging 2, 5, and 10 Values Together

- 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

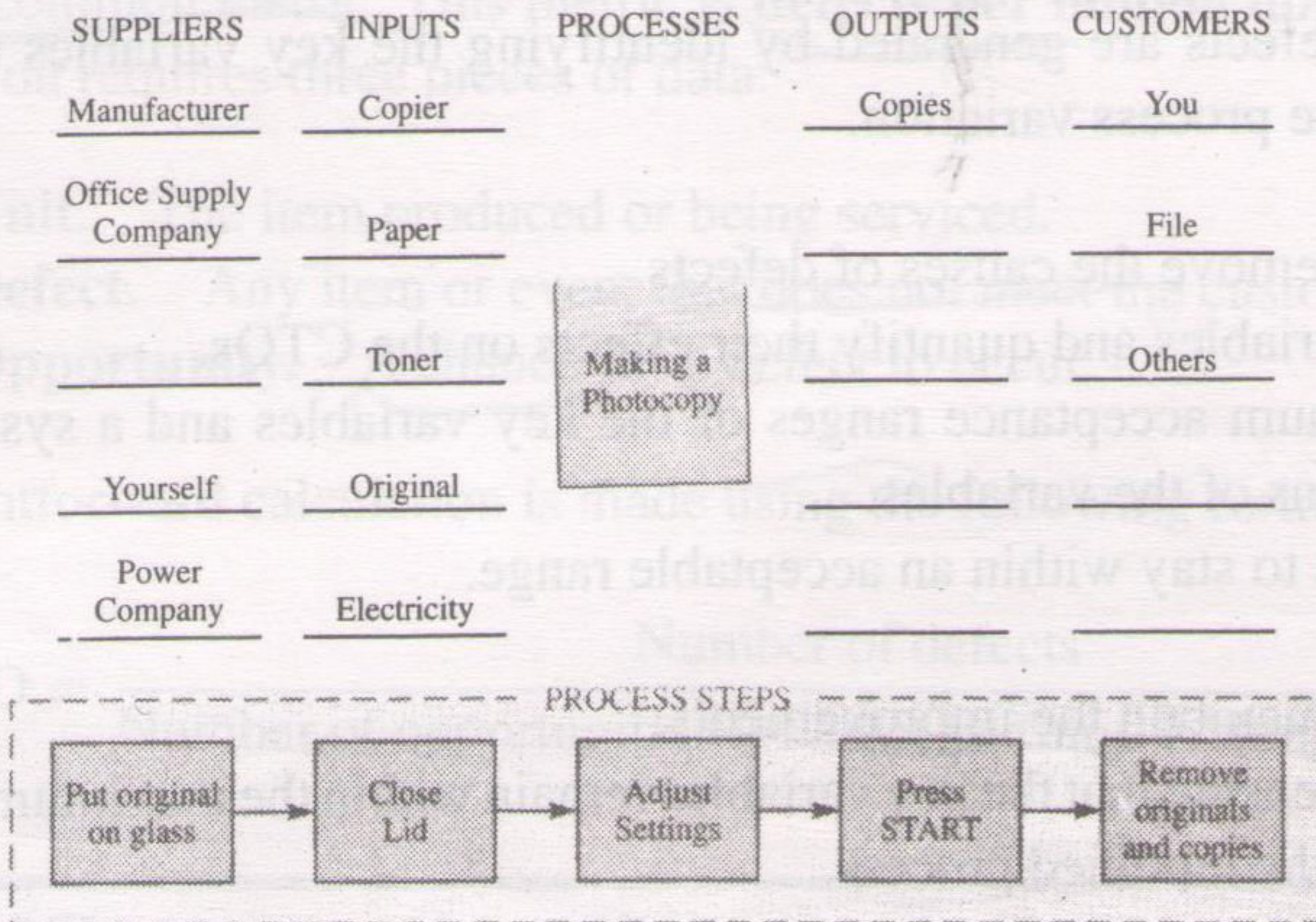
- Typical six-sigma projects are four to six months in duration and are selected for their potential impact in the business.
- Six-sigma uses a specific five-step problem solving approach: Define, Measure, Analyze, Improve, and Control (DMAIC).

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.

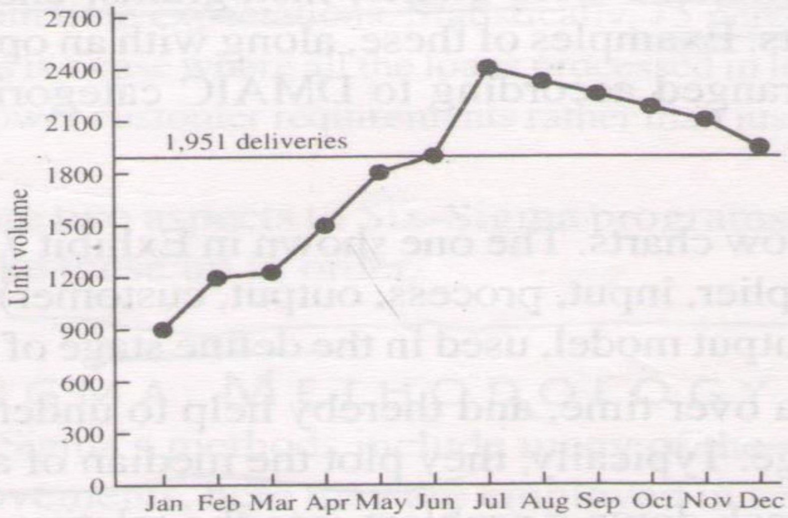
Flow Chart of Major Steps in a Process*

Define



Run Chart**

Average monthly volume of deliveries (per shop)



DATA COLLECTION FORMS*

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

Defines what data are being collected → **Machine Downtime (Line 13)**

Operator: Wendy Date: May 19

Reason	Frequency	Comments
Carton Transport	~~IIII~~ ~~IIII~~ II	
Metal Check	IIII	
No Product	~~IIII~~ I	
Sealing Unit	II	
Barcoding	III	
Conveyor Belt		
Bad Product	~~IIII~~	Burned flakes III Low weight II
Other	II	

Lists the characteristics or conditions of interest

Includes place to put the data

May want to add space for tracking stratification factors

Has room for comments

Measure

Pareto Chart**

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

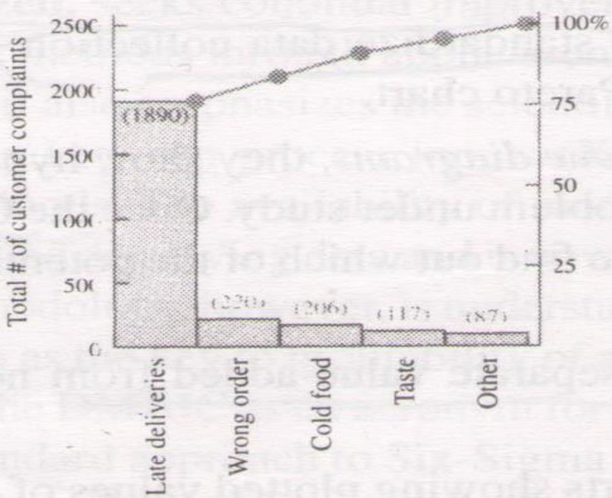
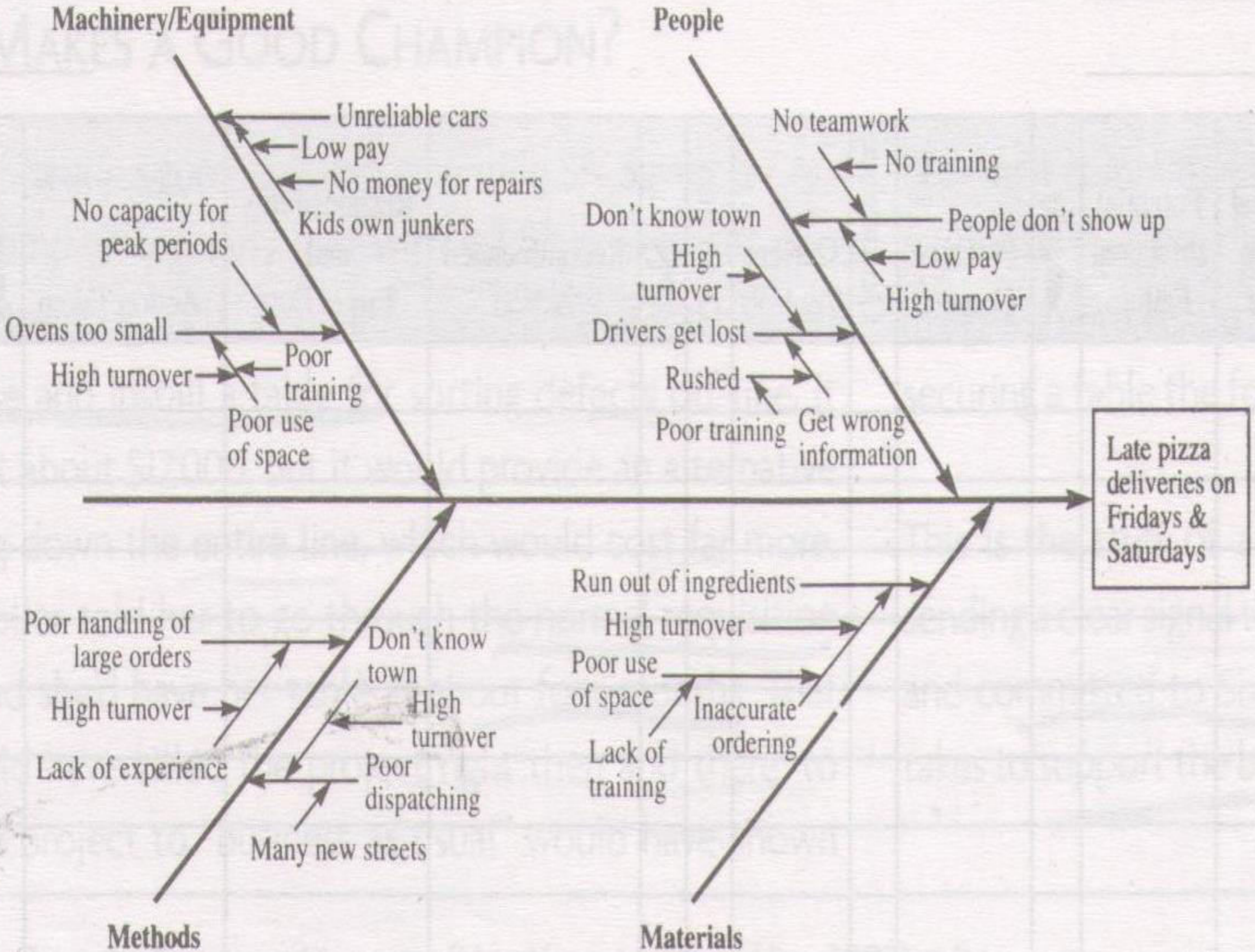


Illustration note: Delivery time was defined by the total time from when the order was placed to when the customer received it.

C & E/Fishbone Diagram**

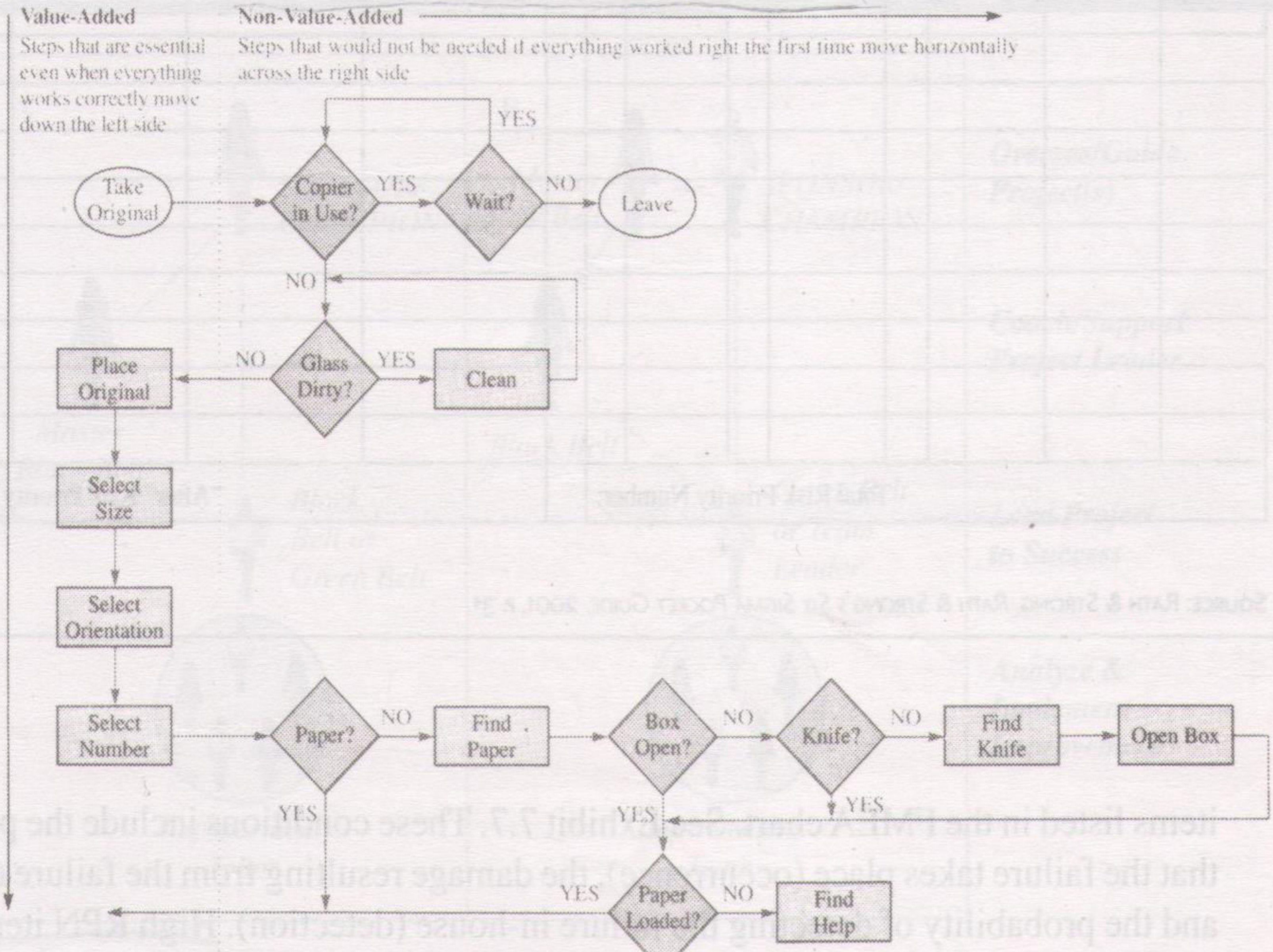
Reasons for late pizza deliveries

Analyze



Opportunity Flow Diagram*

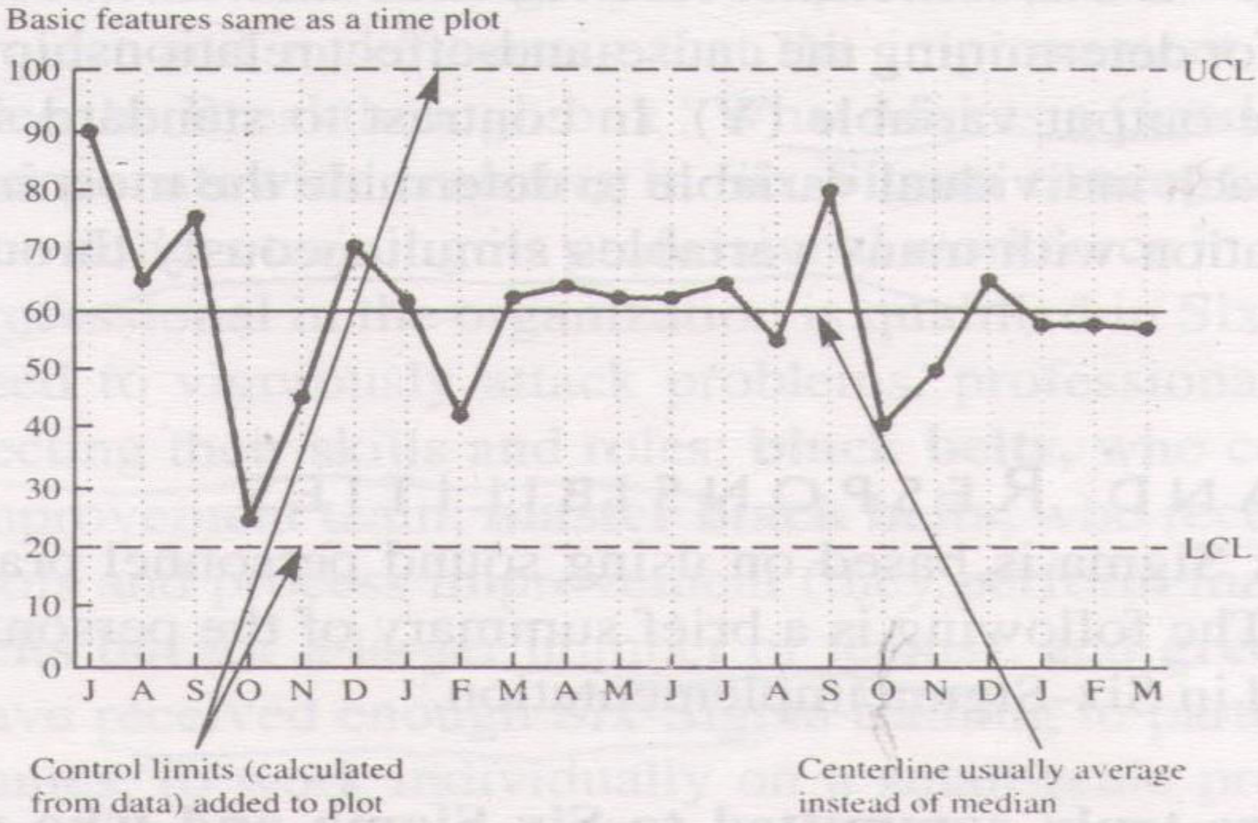
Organized to separate value-added steps from non-value-added steps.



Improve

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?

$$P(\text{Single meal good}) = (0.99)10 = 0.9044$$

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

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

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

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

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

Structure of a typical six-sigma organization

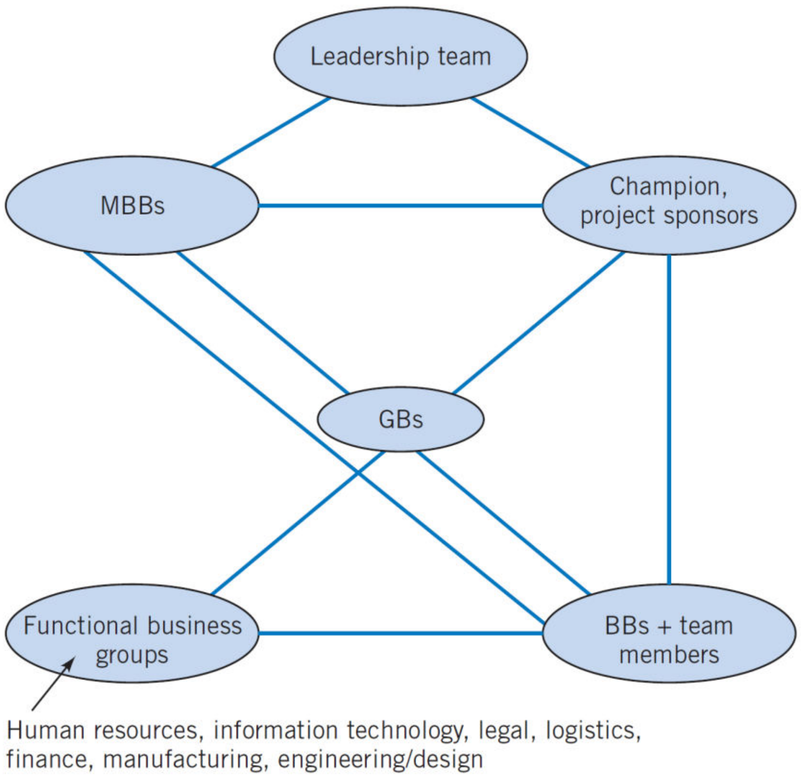


Figure 2.6 The Structure of a Six-Sigma Organization

(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.

design for six sigma

- 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.

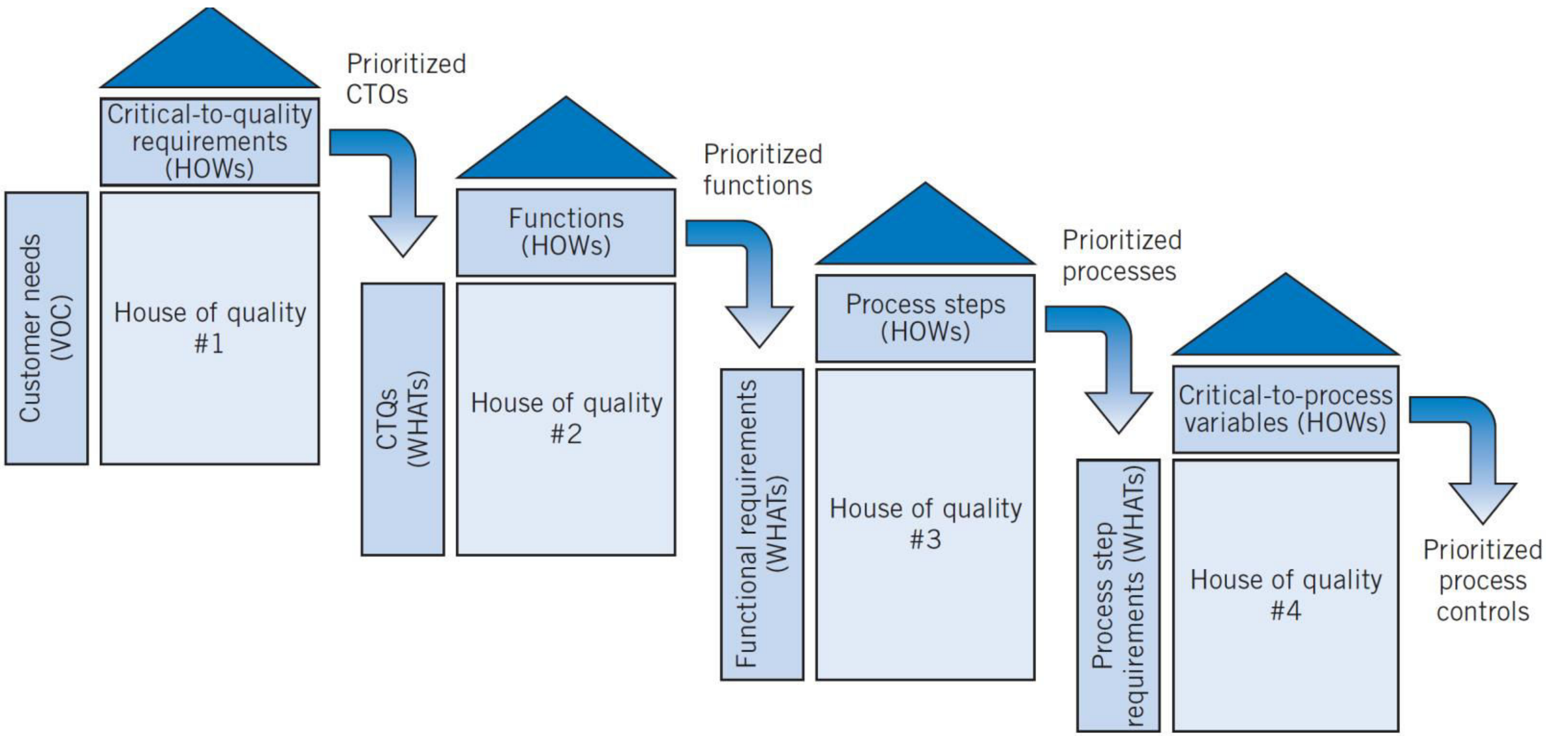
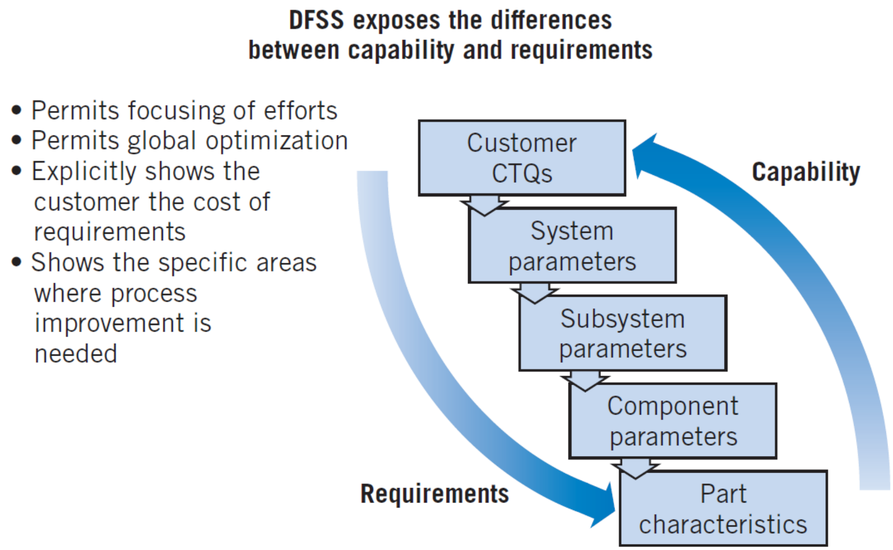


Figure 2.7 A Four-Step Quality Function Deployment Process

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.

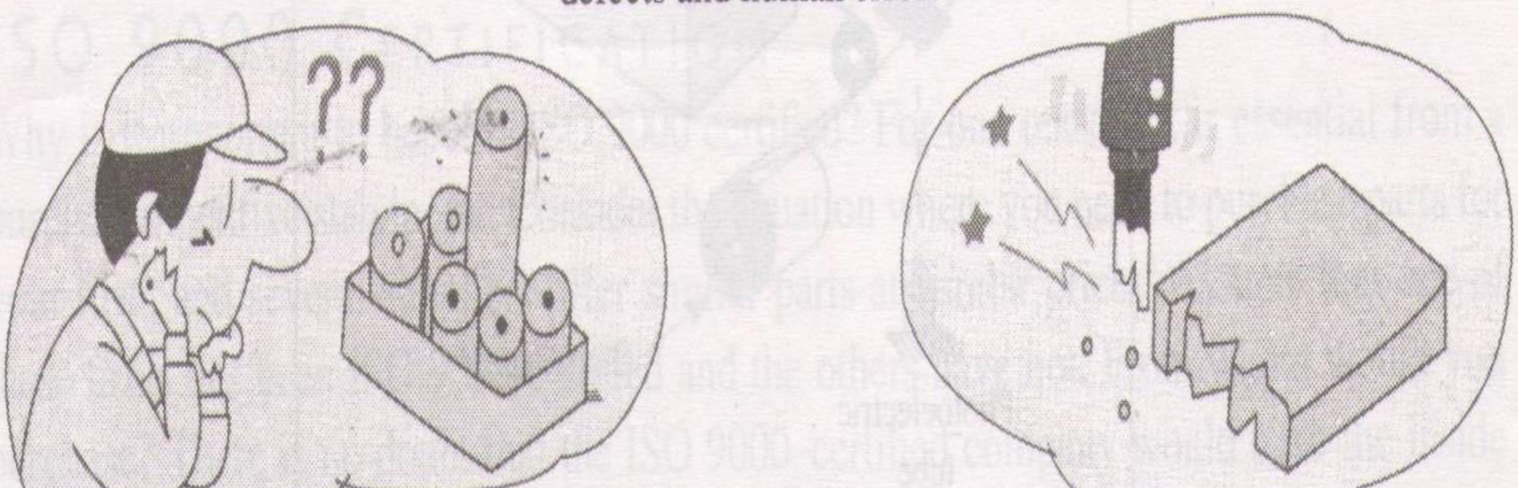
What Are the Sources of Defects?

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

Causes of Defects \ Human Errors	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

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 investigation?	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

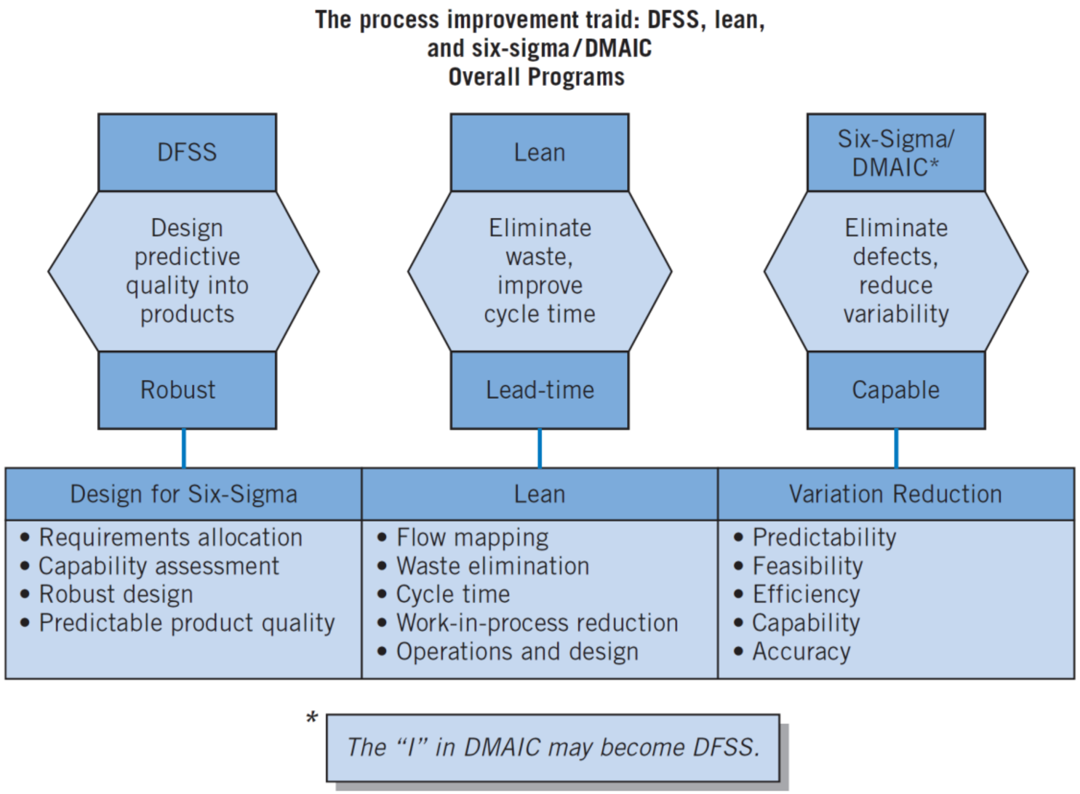
Identify causes of the failure modes and controls

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.