Production, Quality, and Manufacturing

3.7.2

SEAPOWER THROUGH ENGINEERING

TOPIC LEARNING OBJECTIVES

Upon successful completion of this topic, the student will be able to:

1. Recognize the elements of manufacturing (5Ms) as they relate to designing a production program.
2. Recognize the considerations/concerns of the elements of manufacturing (5Ms) and how other areas are affected (i.e., design and producibility).
3. Distinguish between process and product structures.
4. Identify the impact of variability on process and product performance.
5. Identify methods of controlling manufacturing costs (e.g., process proofing, variability reduction, and statistical process control).
6. Relate process performance to specification tolerance and process capability.
7. Recognize the value of Lean Manufacturing.
8. Relate the DoD Quality Systems policy and the role of ISO 9001 in an acquisition program.
9. Recognize the value of the cost of quality.
10. Recognize that the use of the "5 Whys" root cause determination method is used in identifying potential root causes.
11. Recognize that the multi-voting technique is used to narrow large lists of possibilities into smaller, more manageable lists.
12. Analyze the elements of manufacturing as they relate to a systems performance problem using a qualitative tool (cause and effect/fishbone diagram).

STUDENT PREPARATION

Student Support Material

1. None

Primary References

1. DoD 5000 series
2. Defense Acquisition Guidebook

Additional References

1. "Defense Acquisition Management Framework Chart"
2. DOD Manufacturing Technology (MANTECH) Program website: https://www.dodmantech.mil/
3. Navy Performance Improvement Education Resource (NPIER) website:

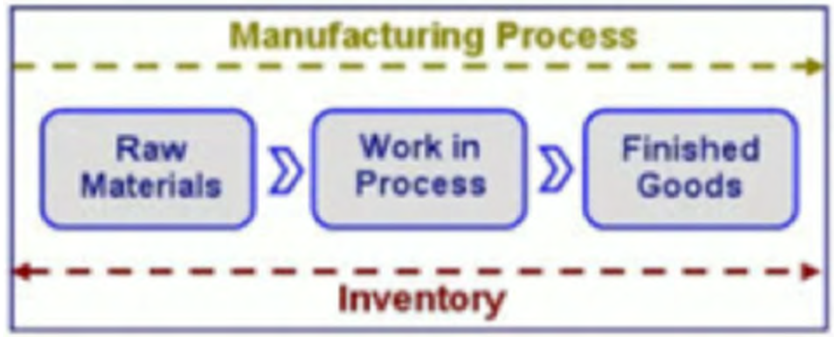
Overview

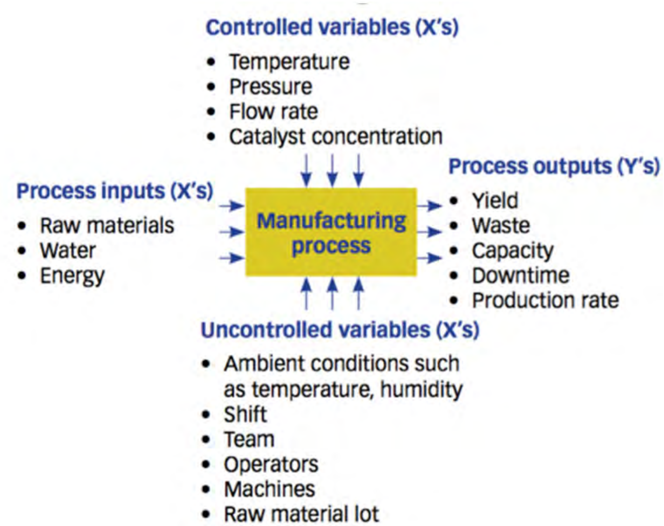
- Elements of the manufacturing process
- Process and product structures
- Variability
- Controlling manufacturing costs
- Lean manufacturing
- Problem solving techniques
- DoD quality systems policy

Manufacturing

- Conversion process that:
  - Takes raw materials and transforms them into a finished product
  - Translates the systems engineering specifications into a deliverable system

- The transformation from raw materials to finished product requires
  - A design
  - A set of processes
  - A set of process controls





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5Ms of Manufacturing

- A design is transformed into a finished product by a manufacturing process
- The manufacturing process must also be designed
- 5 basic elements are examined prior to manufacturing:
  1. Material
  2. Machinery
  3. Method
  4. Manpower
  5. Measurement
- The 5Ms of manufacturing and the process structure will impact the design for producibility

The 5Ms of manufacturing are used to ensure the system design is produced into a uniform, defect-free, reproducible product

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Product Structures

- Product structure describes the product in terms of volume and standardization
  - Volume – quantity of items produced
  - Standardization – items produced within a set specification
- Four types of product structures:
  1. Low volume, low product standardization (unique products)
  2. Fairly low volume, multiple products
  3. Higher volume, few major products
  4. High volume, high product standardization (one product)

The product structure determines the process structure needed to produce the desired end item

Process/Product Structure Continuum

Process Structure

- Job Shop
  - Satellite
  - Ships (maybe)
- Batch
  - Aircraft
  - Tanks
  - Ships (maybe)
- Assembly Line
  - Radios
  - Mass-produced components
- Continuous Flow
  - Fuel oil
  - Bullets

Product Structure

- Low volume, low product standardization (unique products)
- Fairly low volume, multiple products
- Higher volume, few major products
- High volume, high product standardization

Increasing product volume and standardization

Product/Process Structures

- ***Product structure: low volume, unique products***
- ***Process structure: job shop or jumbled flow***
  - A manufacturing process devoted to producing special or custom-made parts
  - Small quantities for specific customers; many physically unconnected processes and/or machines allowing great process flexibility (e.g., satellite production)

Product/Process Structures

- ***<u>Product structure: fairly low volume, multiple products</u>***
- ***<u>Process structure: batch</u>***
  - A manufacturing process devoted to producing similar parts or end items in specific lots with discrete start and stop points for each lot
  - Typical defense items include missiles, aircraft, and spare parts

Product/Process Structures

- ***Product Structure: high volume, few products***
- ***Process Structure: assembly line***
  - A manufacturing process devoted to producing a standardized, identical product in large quantities
  - Items are mass-produced, passing through a series of stations, each performing a task and using interchangeable parts
  - Typical U.S. automobile production

Product/Process Structures

- ***<u>Product structure: high volume, high product standardization, commodities</u>***
- ***<u>Process structure: continuous flow</u>***
  - A manufacturing process devoted to producing high volume products
  - May be continuous in nature vice discrete units
  - Interchangeable parts and standardization of assemblies are required
  - Common examples are bullets or fuel oil production

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Variability

- Variability is the tendency to deviate from an established specification
- Specifications are limits called out by contracts, blueprints, drawings, Initial Capabilities Document (ICD), etc.
- Variability:
  - Will affect process and product performance
  - Always exists to some degree
  - Is caused by 5Ms + Environment (Milieu) = 6Ms
- Instability of requirements and design will cause churn (including specification churn) and ***negatively impact program cost and schedule***
- Instability of ***production processes produces variability***

There is inherent variability in both product and process performance (it cannot be reduced to zero)

Variability in Process Performance

- A production process is a system of operations to produce an end product (such as steps an operator takes on an assembly line)
- Examples of variability on process performance:
  - Manpower: skill level, motivation, training
  - Machinery: re-tooling, setting of parameters
  - Method: different methods used to obtain product
  - Measurements: measurement techniques may change between shifts
  - Material: different stock vendors may provide dissimilar material
  - Milieu or environment: temperature, humidity

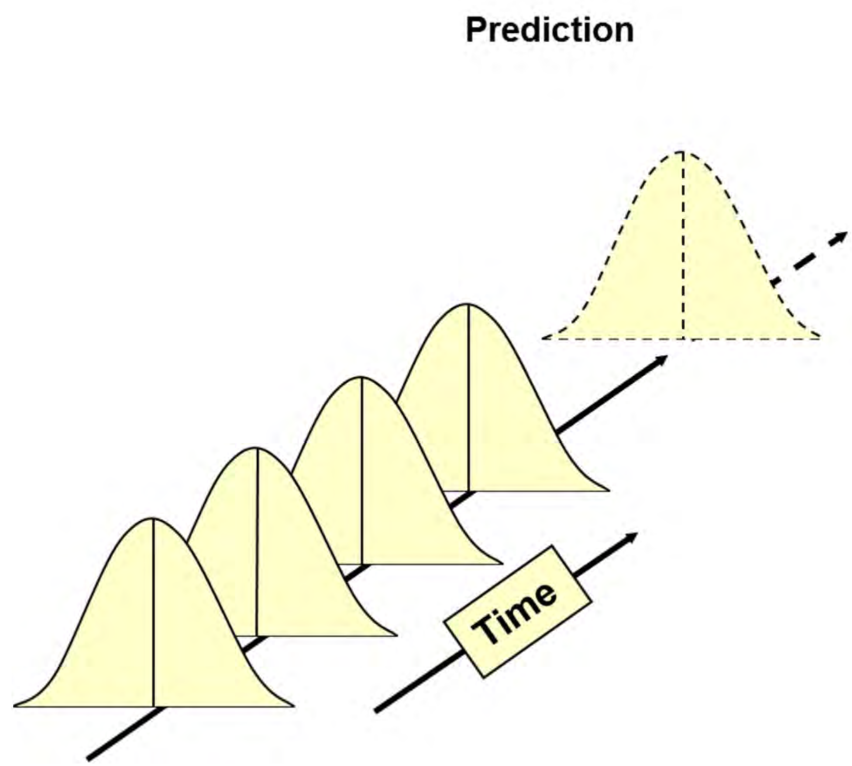
Variability in Product Performance

- Variability in form, fit, and function:
  - Performance degradation
  - Reduced product availability (it breaks more often)
  - Parts tolerance increased (doesn't fit like it should)
  - Product does not meet specifications (range, speed, payload)
- Variability in the end product may drive quality issues which ***negatively impact program cost and schedule***

Variability in processes will be seen as variability in the end product's form, fit, & function

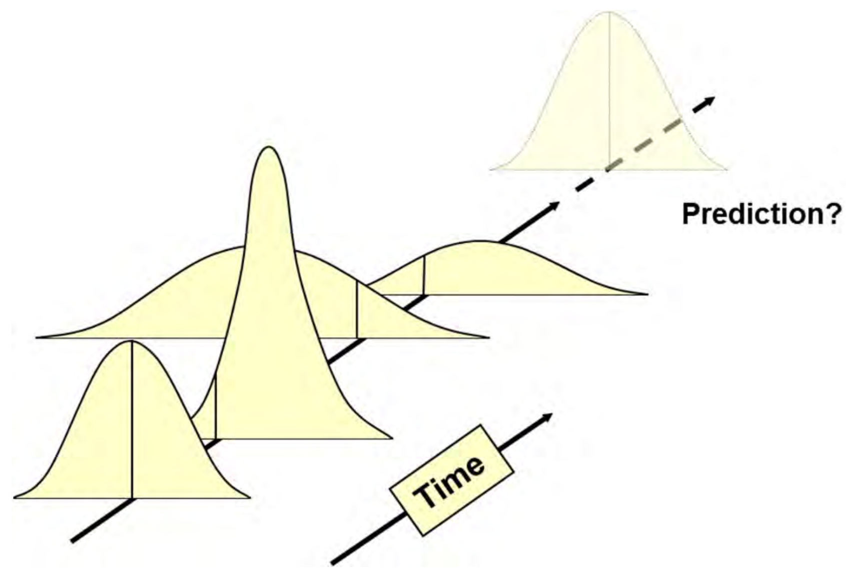
Variation: Common Causes

- If only common causes of variation are present, the output of a process forms a distribution that is stable over time and is predictable
- “Noise” in the process
- Examples of common causes:
  - Machine vibration
  - Slight raw material variation
  - Slight worker method variation



Variation: Special Causes

- If special causes of variation are present, the process output is not stable over time and is not predictable
- “Signal” in the process
- Examples of special causes:
  - Operator error
  - Defective raw material
  - Faulty setup



Manufacturing Limits

- Example: A contract calls for a manufacturer to produce a fastener to 1 inch +/- 0.025 inches
- Control limits are mathematically determined and are dependent on
  - Range of your samples
  - Sample size
  - Constant for variable control

USL = Upper Specification Limit

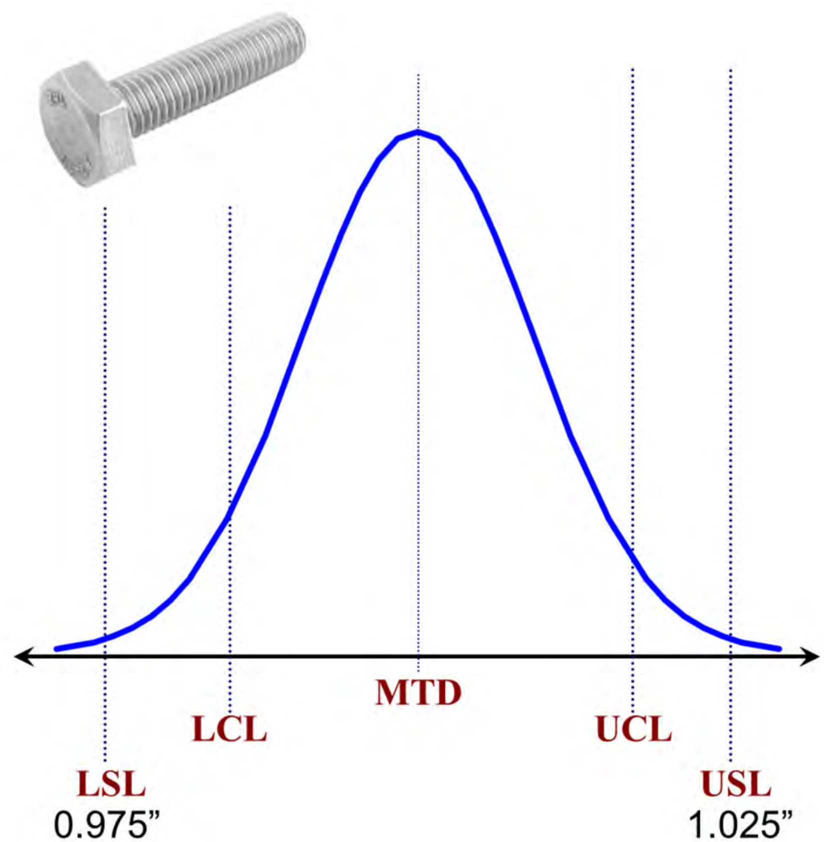
LSL = Lower Specification Limit

T = Tolerance (USL-LSL)

MTD = Mid Tolerance Dimension

UCL = Upper Control Limit

LCL = Lower Control Limit



Process and Product Performance

Specification limits of the product

- Spec. limits are given
- Based on needed performance of the product
- Tell us how to disposition the product
- ***Spec. limits measure product consistency***

Control limits of the process

- Are mathematically determined from process data
- Based on performance of the process
- Tell us when to take action on the process
- ***Control limits measure process consistency***

A successful manufacturing program will determine which manufacturing processes are the most important in affecting product performance

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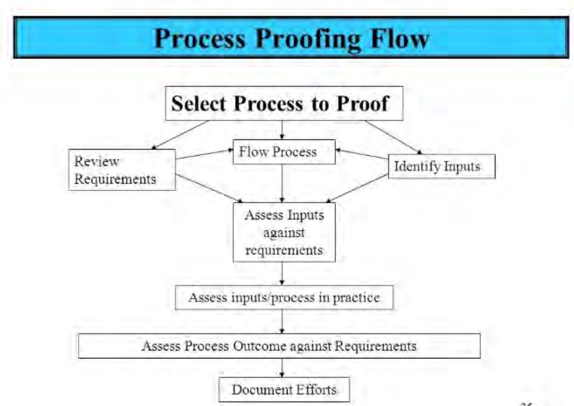
Controlling Manufacturing Costs

- There are three key elements in the manufacturing process that are common methods to control manufacturing costs:
  1. Process proofing
  2. Variability analysis
  3. Statistical Process Control (SPC)

Process Proofing

- A systematic series of actions to establish objective evidence to support whether a process consistently produces the desired result
- Done prior to the start of production and attempts to measure the effectiveness of proposed production processes (like a dress rehearsal)
  - Aimed at manufacturing and support processes critical to achieving requirements
  - Simulates actual production environment & conditions
  - Ensures repeatedly conforming hardware & software
  - Used as a risk mitigation tool



Source: Kaylyn Wiswell, https://slideplayer.com/user/4663433/

Process proofing reduces manufacturing risk, if done early in the program

Variability Analysis

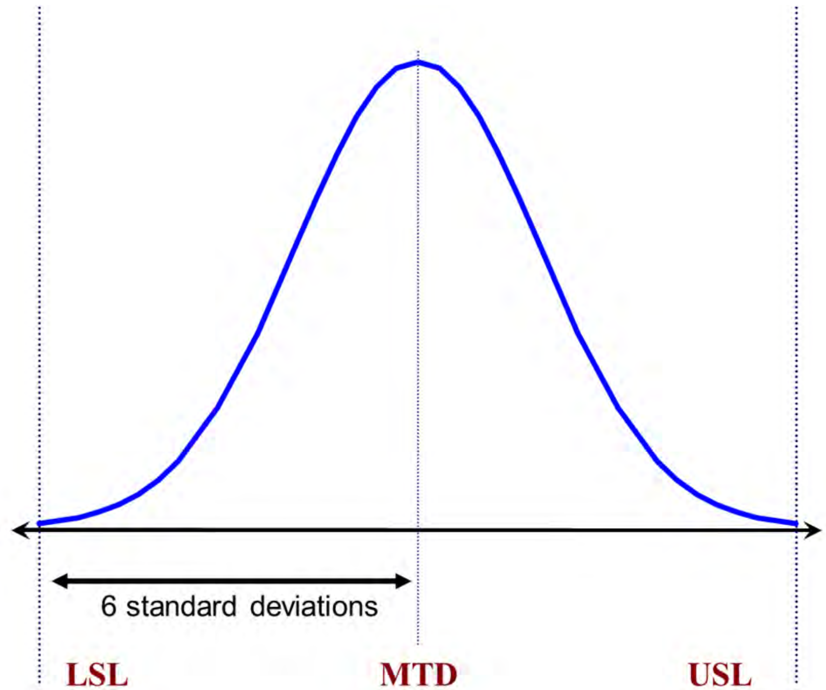
- Variability analysis: the basics of Six Sigma
  - General Electric's definition of Six Sigma
    - Six Sigma is the discipline's methodology of defining, measuring, analyzing, improving, and controlling (DMAIC) the quality in every one of the Company's products, processes and transactions-with the ultimate goal of virtually eliminating all defects
  - Six Sigma complements Lean manufacturing principles
  - Six Sigma seeks variability reduction in:
    - Design
    - Suppliers/vendors
    - Incapable processes
    - Measurement

6sigma.us

Basics of Six Sigma

- Six Sigma refers to a process having six standard deviations between the process mean and the nearest specification limit

- σ = standard deviation
- +/- 1σ: 68.26% within spec.
- +/- 6σ: 99.99966% within spec.



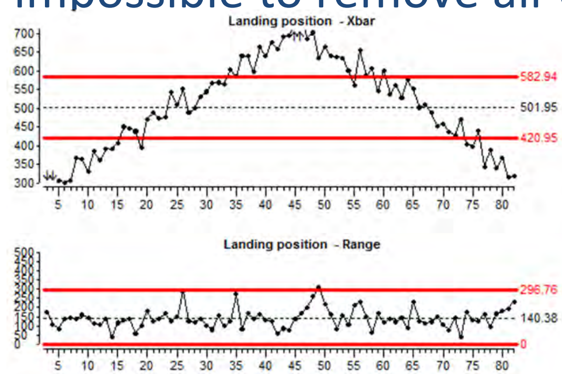
Sigma Comparison

- Six Sigma allows managers to readily describe/compare process performances using a common metric:
  - Defects Per Million Opportunities (DPMO)
- $DPMO = \frac{Number\ of\ Defects}{\left(\frac{Number\ of\ Opportunities\ for\ Error}{Unit}\right) \times Number\ of\ Units} \times 1{,}000{,}000$

Sigma Benchmarks		
Process	σ	DPMO
IRS Phone-in tax advice	2.2	241,964
Average manufacturing company	3.0	66,807
USN aircraft accidents	5.7	13
Watch error of 2 seconds in 31 years	6.0	3.4
Airline industry fatality rate	6.2	0.43

Statistical Process Control

- A method of visually monitoring manufacturing processes
  - Uses ‘control charts’
  - Pioneered by Deming prior to and during WWII
- Introduced to Japanese after WWII and instilled in their manufacturing culture
- Deming and others showed that it is impossible to remove all variation from a process
  - Common cause variation
  - Special cause variation



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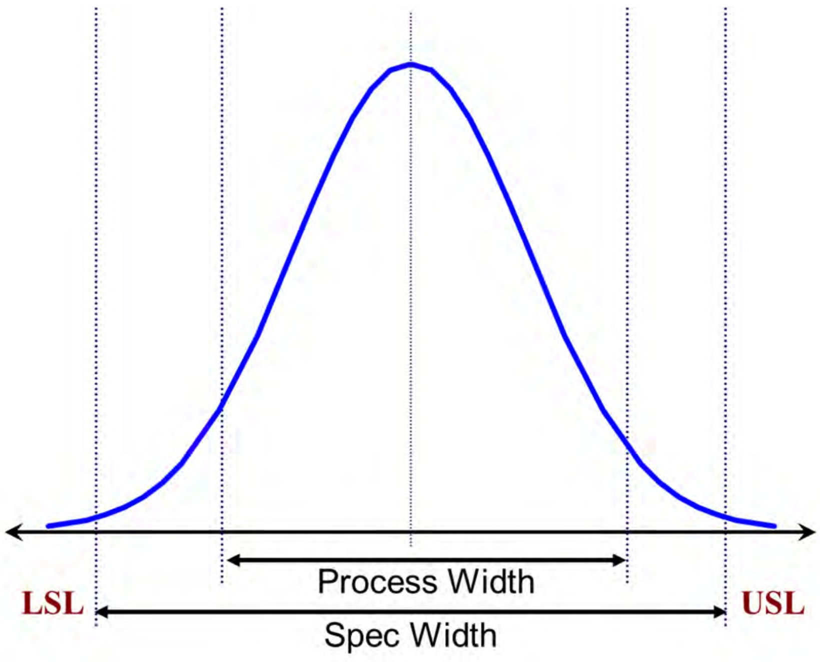
SPC relates process performance and specification tolerance to give a measure of process capability

Process Capability (C_p)



- Is the process capable of meeting specifications?

- $$C_p = \frac{USL - LSL}{6\sigma}$$

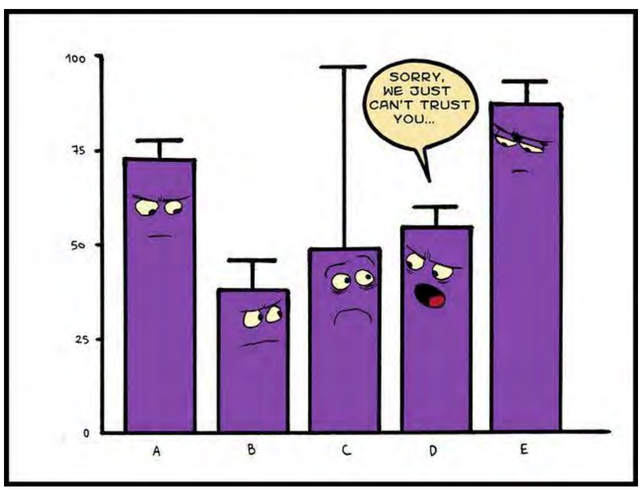
$$Process\ Capability = \frac{Specification\ Width}{Process\ Width}$$

C_p	Decision
< 1.0	Not Capable
1.0 – 1.33	Marginally Capable
> 1.33	Capable
≥ 2.0	6σ Quality

A measure of process capability for a known process width and specification tolerance

Six Sigma/SPC

- Six Sigma Quality programs use SPC to:
  - Bring the process into statistical control
    - Ensure that only common cause variation is present
    - Special cause variation is eliminated
    - Process is stable and predictable
  - Determine if the process is capable of meeting specs
    - Relates spec. tolerance and process performance to determine process capability (C_p)
  - Make decisions on how to improve the process



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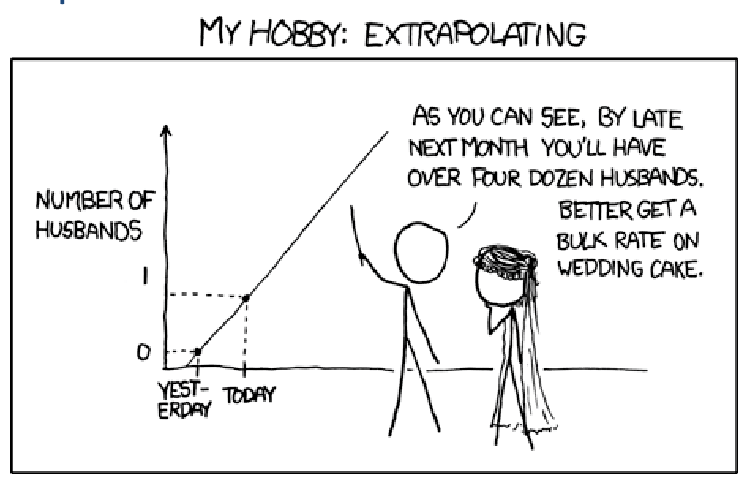

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Lean Manufacturing

- Lean is a people-oriented business philosophy
- Five principles of Lean
  1. Provide ***Value***, as identified by the customer
  2. Identify the ***Value Stream***
  3. Make the process ***Flow***
  4. Use customer ***Pull*** to initiate action
  5. Pursue ***Perfection***

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Two main goals of Lean manufacturing are: (1) minimization of waste and (2) responsiveness to change

Lean Manufacturing

- Manufacturing has evolved through the ages
  - Craft-based
  - Mass production
  - Agile, Lean systems
- DoD guidelines do not require Contractors to use Lean manufacturing systems
- Businesses have been drawn to Lean manufacturing because Lean manufacturing enables them to:
  - Produce at reduced cost
  - Be more competitive in the marketplace
  - Better meet customer demand

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5 Whys

- Question-asking method to explore cause/effect relationship and underlying issues
- "Five" is guideline, not a hard-and-fast rule
- Three key elements to effective use:
  - Accurate, complete problem statement
  - Complete, unbiased, honest answers to each "why"
  - Determination to find root cause and not just symptoms
    - Correcting symptoms wastes resources
    - Correcting root cause gets rid of problem permanently

Multi-voting

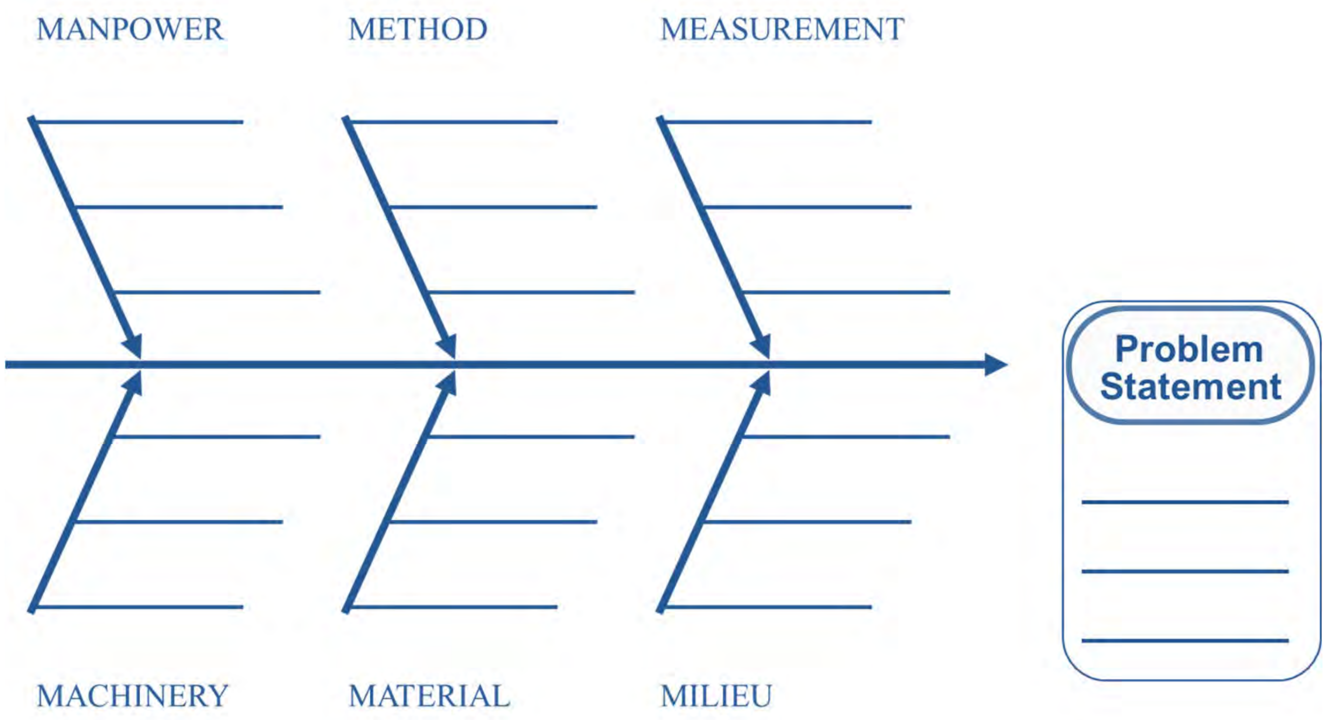
- Narrows large list of possibilities to smaller list of top priorities
- Preferable to straight voting – allows item that is favored by all, but not top choice of any, to rise to top
- When to multi-vote:
  - After long list of possibilities has been generated
  - List must be narrowed down
  - Decision must be made by group judgment
- How to multi-vote (one variation):
  - Display list of options, combining duplicate items
  - Working individually, members select a pre-determined number of items (typically 3-5) thought to be most important
  - Tally votes – votes can be prioritized and weighted, if desired
  - Repeat process if necessary to further reduce list of options
  - Further investigate and/or refine top vote-getters

Problem Solving Exercise

- Valve-Regulated Lead Acid (VRLA) battery installations are behind schedule
  - Significant schedule slip is from rework during the cabinet installation phase
  - This is the third VRLA battery installation
  - The first installation occurred 8 months ago
  - The installation team has had 15% turnover from previous installs
  - This is the first installation at NNSY
  - This is the first installation on a Flight II SSN
- There are more installations to follow! How will you proceed differently to improve the process?

Problem Solving Exercise

- Cause & Effect: Determine considerations and concerns of system design and producibility in this scenario for each of the elements of manufacturing and how other areas are affected:



Problem Solving Exercise

- Brainstorm how to move forward. Ideas should be actionable and relate to design, manufacturing and producibility concerns and considerations
- Resources (funding, manpower, time) are limited. Conduct a multi-vote to determine how to apply resources towards 2 to 4 of the solutions which were brainstormed

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Quality Systems

- Manufacturers need quality systems to provide adequate confidence that a product/service will satisfy customer requirements
- DoD must acquire products that satisfy the needs of the operational user:
  - With measurable improvements to mission accomplishment
  - In a timely manner
  - At a fair and reasonable price
- A Contractor's quality management system should be capable of the following:
  - Establish capable processes
  - Continuously improve processes
  - Monitor and control critical processes and product variation
  - Have feedback mechanisms in place to assess field product performance
  - Implement an effective root-cause analysis and corrective action system

Current DoD guidance allows Contractors to define and use their preferred quality management system as long as it meets program objectives

ISO 9000 Standards Series

- Standards created to set international requirements for quality management systems
- Designed to be applicable to any manufacturing process
- Standards are used in over 80 countries, commonplace usage in the business world
- Countries have published their own ISO version. U.S. version: ANSI-ASQC Q9000 series
- One commercial quality system Contractors may choose is the International Standards Organization (ISO) quality standards:
  - ISO 9001-2000, Quality Management Systems-Requirements
  - AS 9100:2001, Quality Management System-Aerospace Requirements
- Federal Acquisition Regulation (FAR) states that ISO systems are acceptable for use on contracts for complex or critical systems

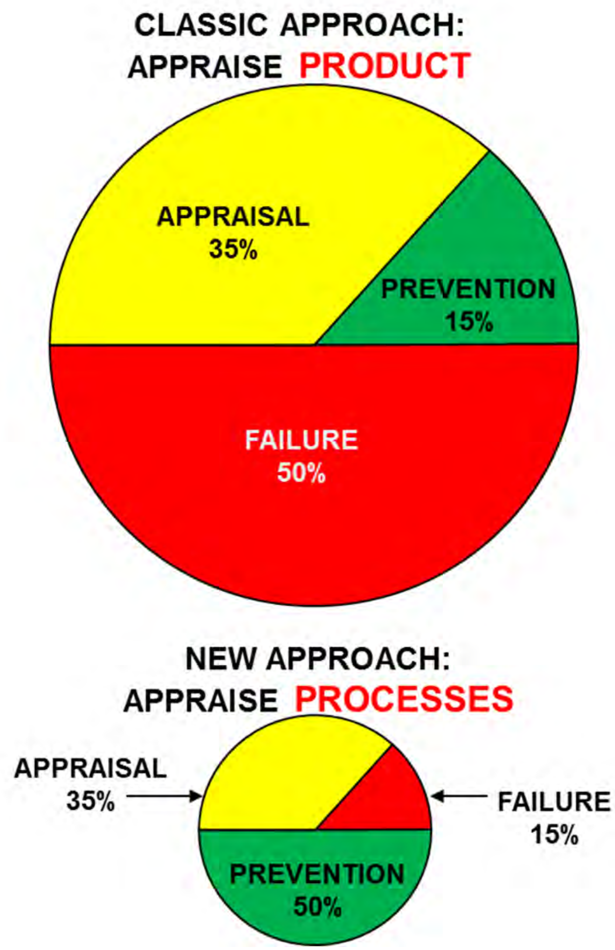
A program manager will not require ISO registration of a Contractor's quality program - ISO compliance is just one means that may be used to distinguish between multiple bidders

ISO 9001

- A standard for Quality Management Systems within the ISO 9000 series
- As a result of acquisition reform in 1994, the ISO 9001 series has been implemented by many Contractors, shifting focus to preventing problems in quality rather than repairing them after they have occurred
- ISO 9001 deals with the fundamentals of quality management systems, including the eight management principles on which the family of standards is based:
  1. Customer focus
  2. Leadership
  3. Involvement of people
  4. Process approach
  5. Systems approach to management
  6. Continual improvement
  7. Factual approach to decision making
  8. Mutually beneficial supplier relationships
- Based on “plan-do-check-act” methodology and is process-oriented
- Certification comes from independent third parties

Cost of Quality

- More upfront costs to avoid defects can save overall money spent on production ($ = size of pie chart). The cost of quality can be broken into three factors:
  - Appraisal
    - Includes money spent on looking for errors (e.g., inspection & testing)
  - Failure
    - Includes money spent to correct errors (e.g., scrap & rework)
      - Internal
      - External
  - Prevention
    - Includes money spent on doing things right the 1st time (e.g., training and processes)



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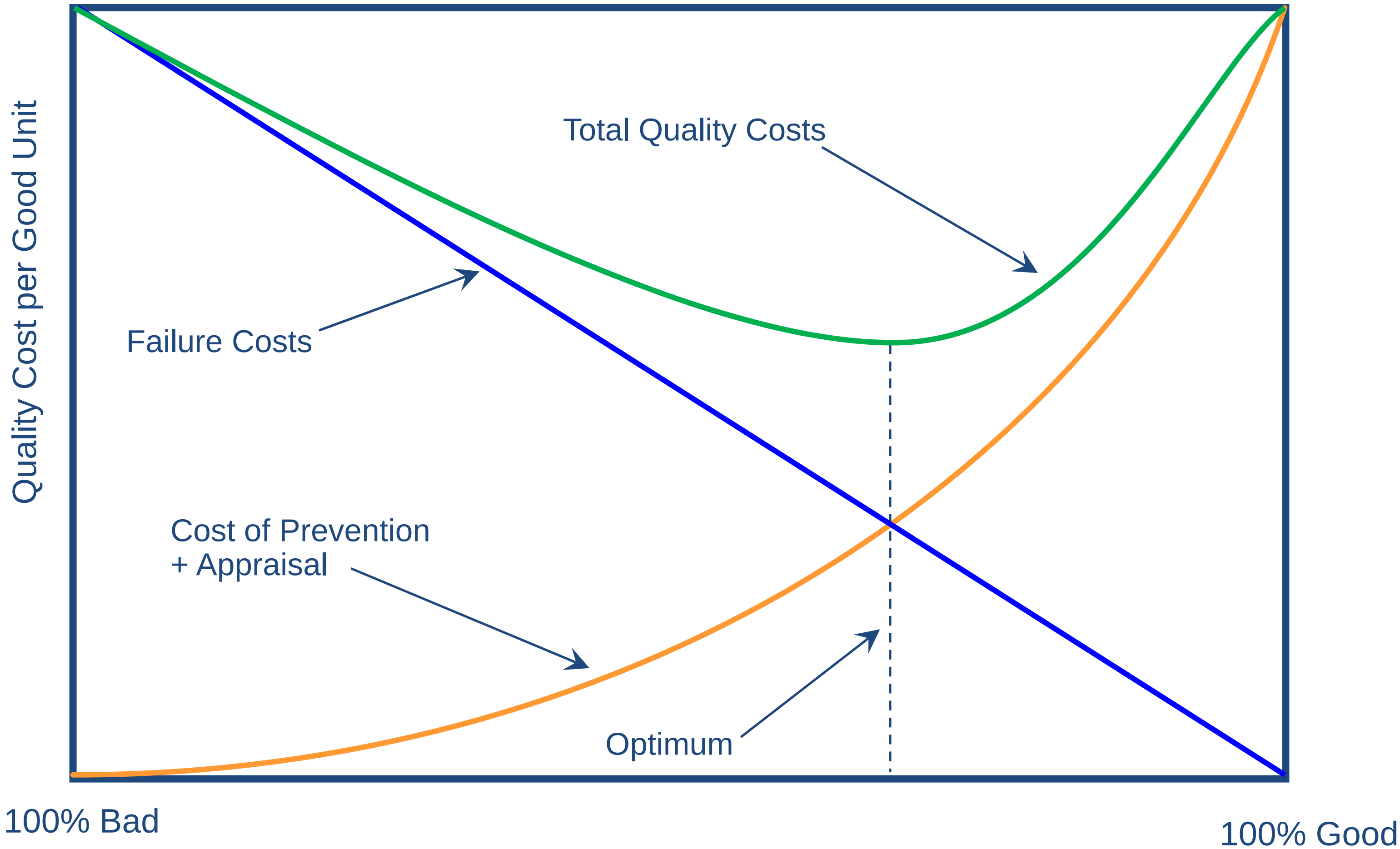
Cost of Quality



Appraisal = cost of looking for errors (e.g., inspection & testing)
Prevention = cost for 1st time quality (e.g., training, process improvement)
Failure = cost to correct errors (e.g., rework, scrap)

Summary

- What are the five basic manufacturing process elements?
- What are the four types of process and product structure?
- How will process variability affect product performance?
- What are three methods of controlling manufacturing costs?

Summary

- What can be determined if you know your process performance and specification tolerance?
- What are the two main principles of Lean manufacturing?
- Why are some businesses moving to Lean manufacturing?
- What is the DoD policy concerning quality programs and ISO 9000/9001?

Summary

- What are three key elements to effective use of the “5 Whys” method?
- Why was 5 chosen in the “5 Why’s” method?
- What is a benefit of the multi-voting technique?
- What conditions indicate that multi-voting would be a good technique to use?