UoG / UESTC Joint School of Engineering

Lecture X: Design for Manufacturing (DFM)

UESTC 3031: Engineering Project Management and Finance

Dr. Duncan Bremner / Dr. Imran Shafique Ansari

Introduction – Design for X

A successful design must consider all relevant considerations throughout the life cycle of a product by analysing the causes and effects of the product

- Design for Manufacturing (DFM)
- Design for Production
- Design for Assembly (DFA)
- Design for Recycling / Disposal
- Design for Life Cycle
- Prototyping

Find out “What is DFMA”: In class Web search….

Design for Manufacturing (DFM)

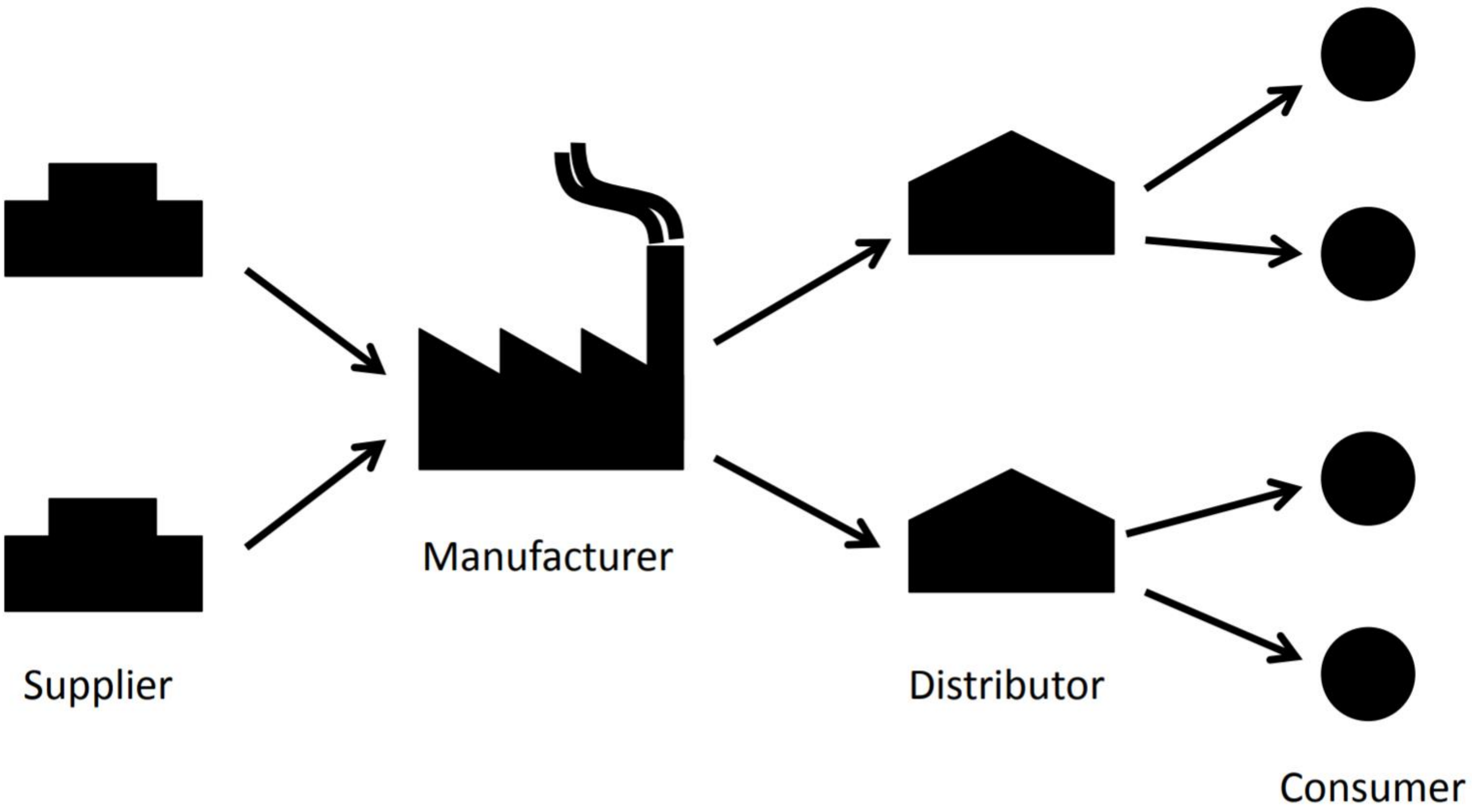
DFM is the process of proactively designing products to:

1. Optimise all the manufacturing functions: Fabrication, assembly, test, distribution …
2. Assure best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction

Concerned with reducing overall part production cost

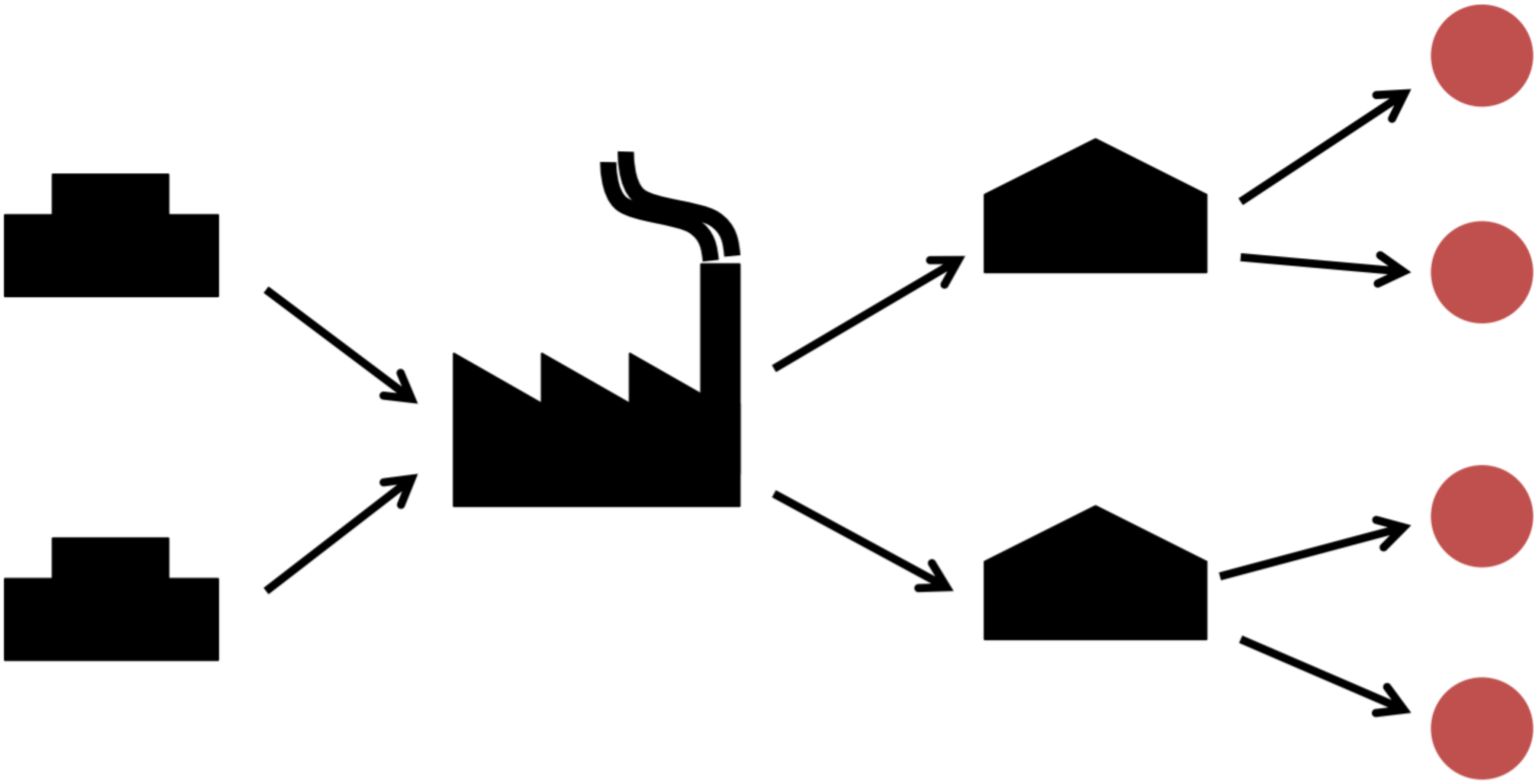
- Minimise complexity of manufacturing
- Use common processes and practices

DFM

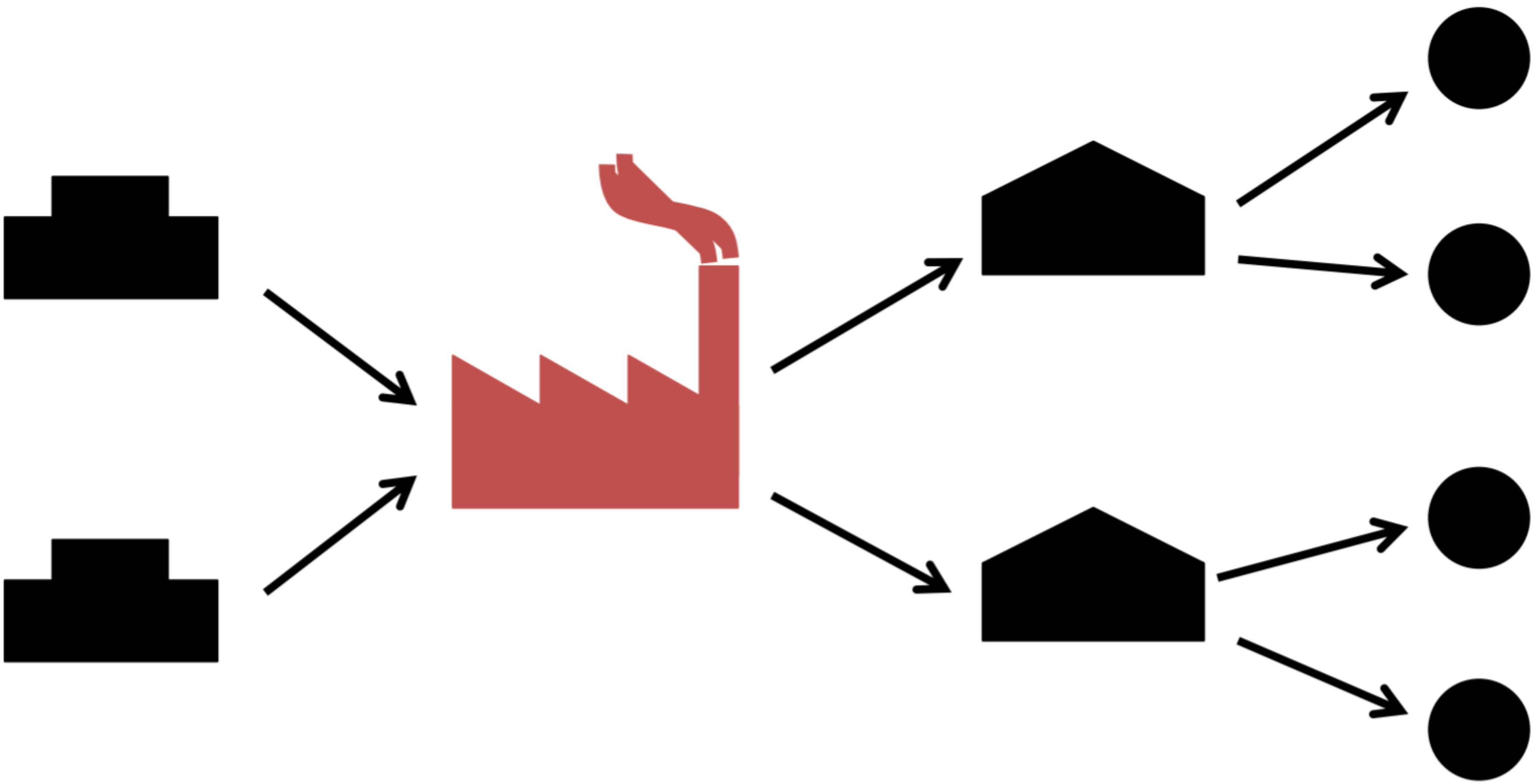


University of Glasgow

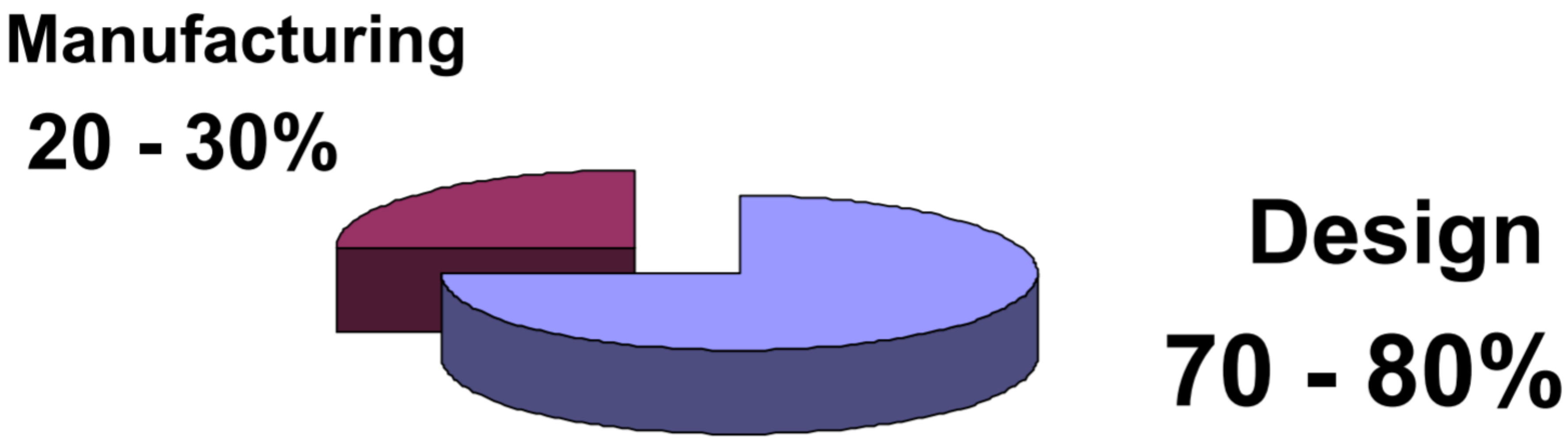
DFM



DFM



Which internal organisation has the most influence over price, quality, and cycle time?

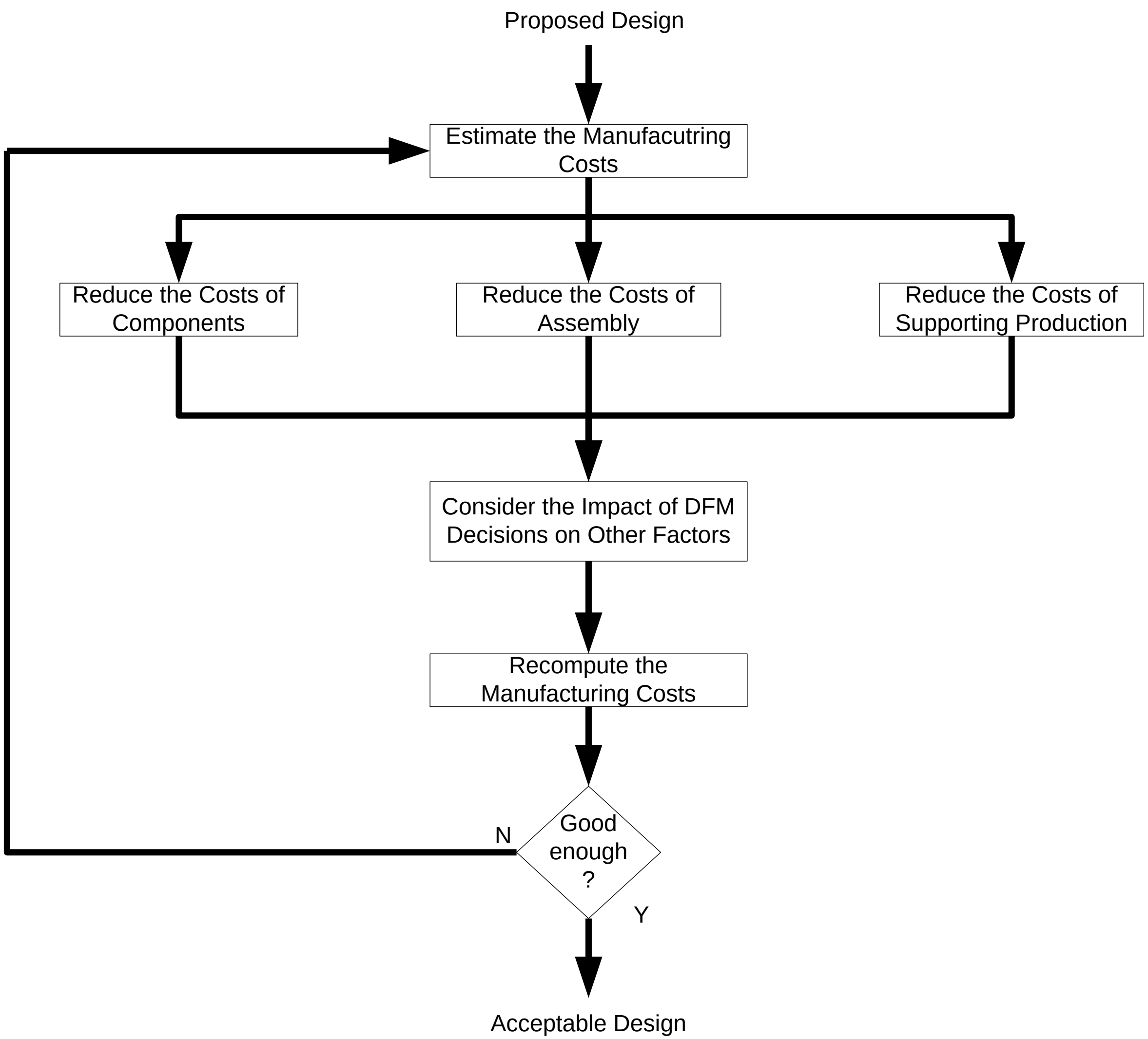


Challenges of Manufacturing

Gathering DFM Information

- Sketches, drawing, product specifications, and design alternatives
- A detailed understanding of production and assembly processes
- Estimates of manufacturing costs, production volumes, and improve timing

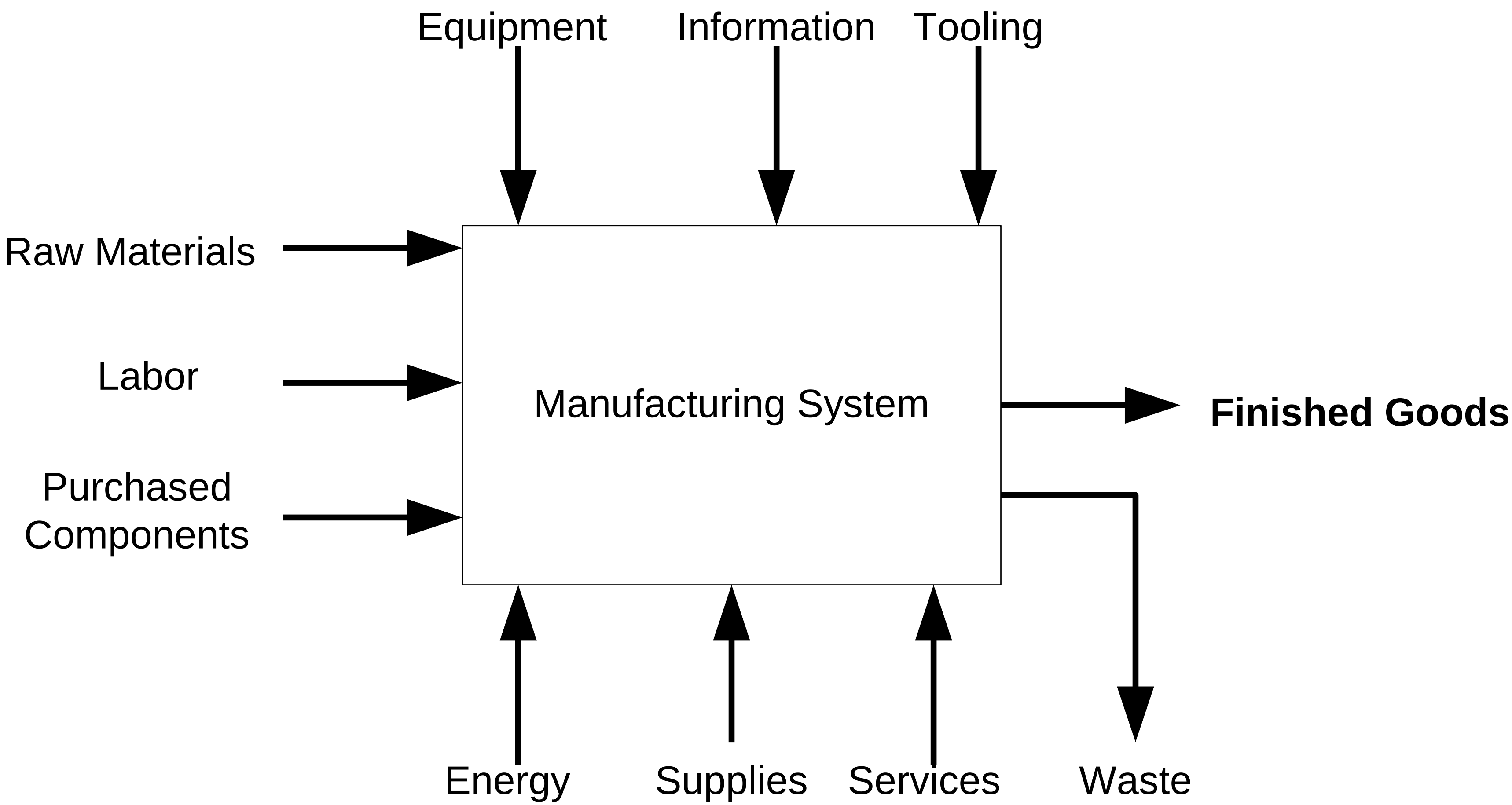
DFM Methodology



DFM Methodology

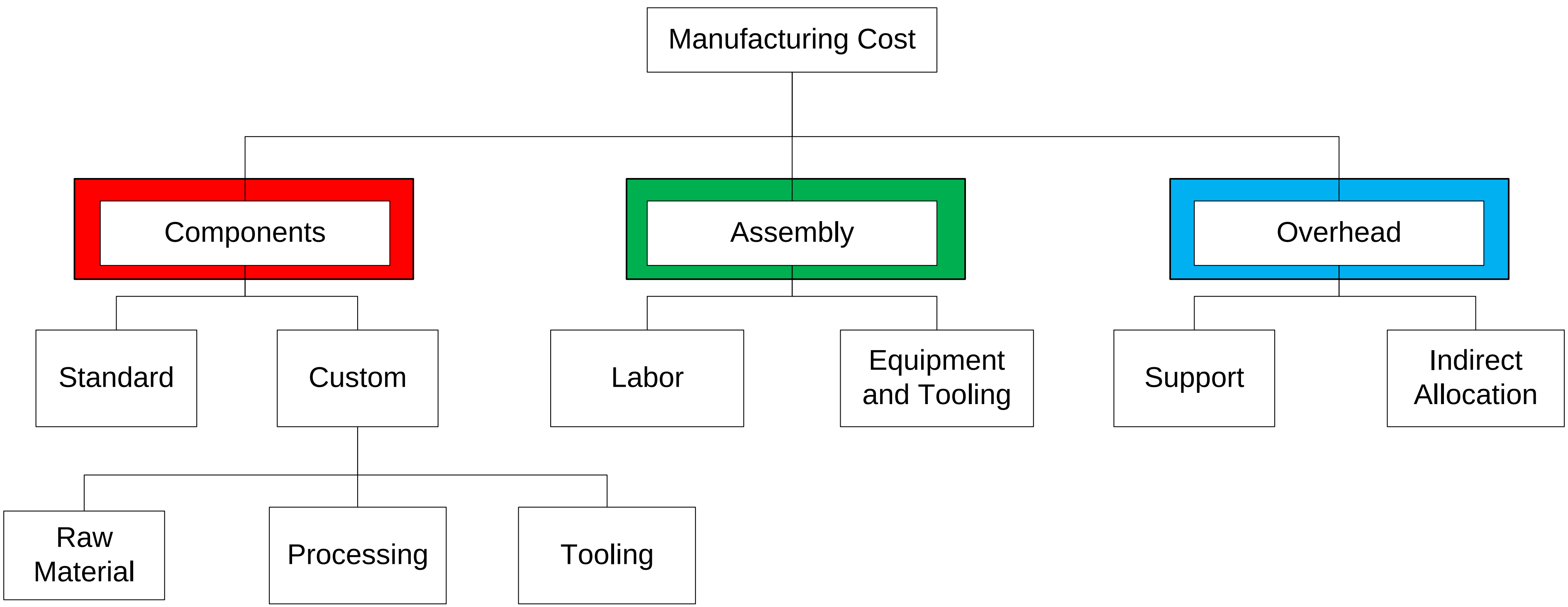
- Estimate the manufacturing costs
- Reduce the costs of components
- Reduce the costs of assembly
- Reduce the costs of supporting production
- Consider the impact of DFM decisions on other factors

Estimating the Manufacturing Costs



Sum of all the expenditures for the inputs of the system (i.e. purchased components, energy, raw materials, etc.) and for disposal of the wastes produced by the system

Elements of the Manufacturing Cost of a Product



Manufacturing Cost of a Product

- Component Costs (parts of the product)
  - Parts purchased from the supplier
  - Custom parts made in the manufacturer’s own plant or by suppliers according to the manufacturer’s design specifications
- Assembly Costs (labor, equipment, and tooling)
- Overhead Costs (all other costs)
  - Support Costs (material handling, quality assurance, purchasing, shipping, receiving, facilities, etc.)
  - Indirect Allocations (not directly linked to a particular product but must be paid for to be in business)

Types of Costs

- *Fixed Costs:* Incurred in a predetermined amount, regardless of number of units produced (i.e. setting up the factory line-up area)
- *Variable Costs:* Incurred in direct proportion to the number of units produced (i.e. cost of raw materials)

Reduce the Cost of Components

- **Understand** the process constraints and cost drivers
- **Redesign** components to eliminate processing steps
- **Choose** the appropriate economic scale for the part process
- **Standardise** components and processes

Understand the Process Constraints and Cost Drivers

- Redesign costly parts with the same performance while avoiding high manufacturing costs
- Work closely with design engineers – Raise awareness of difficult operations and high costs

Redesign Components to Eliminate Processing Steps

- Reduce the number of steps of the production process
  - Usually results in reduced costs
- Eliminate unnecessary steps
- Use substitution steps, wherever applicable
- *Analysis tool:* Process flow-charts and so on …

Choose the Appropriate Economic Scale for the Part Process

- Economies of scale:
  - As production volume increases → Manufacturing costs usually decrease
- Fixed costs get divided among more units
- Variable costs get lowered as the firm can utilise more efficient processes and equipment

Standardise Components and Processes

- Economies of scale: The unit cost of a component decreases as the production volume increases
- Standard components: Common to more than one product
- Analysis tools: Group technology and mass customisation

Reduce the Costs of Assembly

- Design for assembly (DFA) index
- Integrated parts (advantages and disadvantages)
- Maximise ease of assembly
- Consider customer assembly

DFA Index

$$\text{DFA index} = \frac{\text{(Theoretical minimum number of parts) x (3 seconds)}}{\text{Estimated total assembly time}}$$

Determining the theoretical minimum number of parts

- Must the part be made of a different material from the rest of the assembly for fundamental physical reasons?
- Does the part have to be separated from the assembly for assembly access, replacement, or repair?

Integrated Parts (Advantages)

- Do not have to be assembled
- Often lesser expensive to fabricate rather than the sum of each individual part
- Allows critical geometric features to be controlled by the part fabrication process versus a similar assembly process

Integrated Parts (Disadvantages)

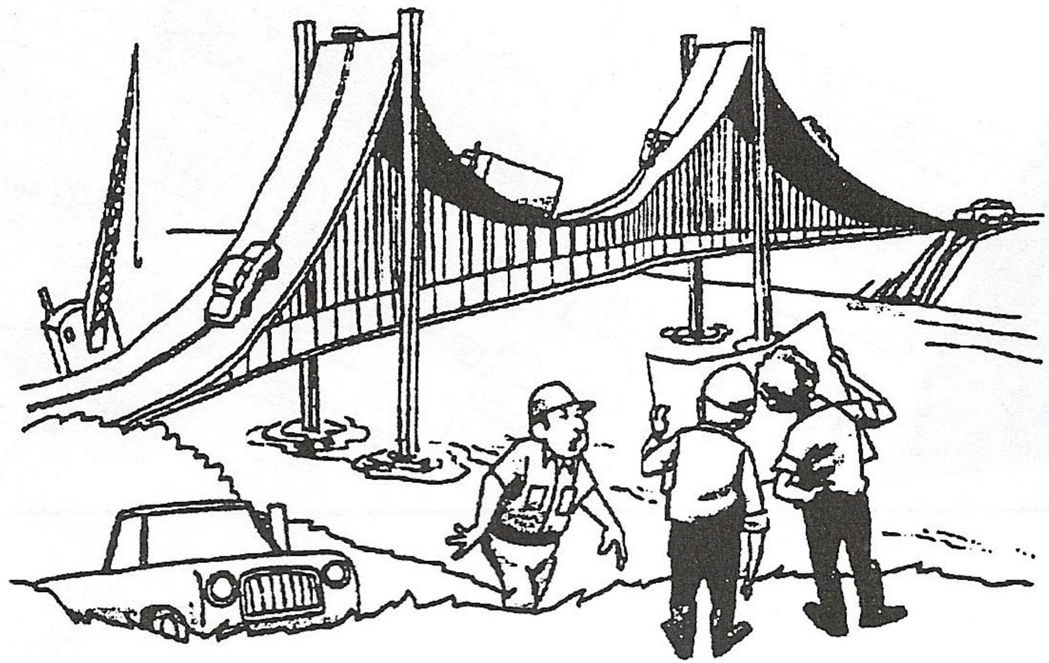
- Conflict with other sound approaches to minimise costs
- Not always a wise strategy

Minimise Ease of Assembly

- Part is inserted from the top of the assembly
- Part is self-aligning
- Part does not need to be oriented
- Part requires only one hand for assembly
- Part requires no tools
- Part is assembled in a single, linear motion
- Part is secured immediately upon insertion

Consider Customer Assembly

- Design product so that customers can easily assemble correctly
- Customers will likely **ignore** instructions!!



"Let me see those blueprints again.!"

Reduce the Costs of Supporting Production

- Minimise systematic complexity (inputs, outputs, and transforming processes)
  - Use smart design decisions
- Error proofing
  - Anticipate possible failure modes
  - Take appropriate corrective actions in the early stages
  - Use colour coding to easily identify similar looking though different parts

Consider the Impact of DFM Decision on Other Factors

- Development time
- Development cost
- Product quality
- External factors
  - Component reuse
  - Life cycle costs

General Principles and Guidelines

- Use common sense
- Plan and define
- Consider available facilities
- Consider available tools
- Consider available worker skills
- Employ simplicity
- Standardise
- Minimise total number of parts
- Develop a modular design
- Minimise part variations
- Design parts to be multifunctional
- Design parts for multiuse
- Design parts for ease of fabrication
- Maximise compliance in assembly
- Minimise handling in assembly
- Minimise complexity of design

Types of Prototypes

- **Physical**
  - Tangible artifacts created to approximate the product
  - Utilised for testing and experimentation

- **Analytical**
  - Represents the product in a nontangible, usually mathematical manner
  - Product is analysed, not built

Types of Prototypes

- **Comprehensive**
  - Implement all (or most) of the attributes of the product
  - Full-scale
  - Fully operational version of the product
- **Focused**
  - Implement a few of the attributes of the product
  - Use two or more focused prototypes together to investigate the overall performance of a product

Component Sourcing

The materials selection process for a component or joint between components involves the following steps:

1. Identify the design requirements
2. Identify the materials selection criteria
3. Identify the candidate materials
4. Evaluate the candidate materials
5. Select materials

Testing

- All test processes are non-value added functions and hence must be kept to a minimum
- Focus on capable and stable processes to produce products that will minimise the requirement for test
- Test planning is the activity of:
  - Designating the stations at which test must be performed
  - Establishing the effectiveness of each test process
  - Identifying which process contributes the most to defects
- Knowing the observed defect level and test effectiveness, we can estimate the submitted defects and escaping defects

University of Glasgow

Types of Testing

- ***Production test:*** Testing of individual products to check whether faults are introduced during the manufacturing phase assuming the design is correct
- ***System test:*** Testing of the product in the environment where it is operating to ensure that it works correctly when interconnected with other components
- ***Burn-in test:*** Testing at elevated temperature and voltage to accelerate and detect early life failures
- ***Operation and maintenance test:*** Testing of the product in the field for diagnosis or preventive purpose
- ***Prototype test:*** Testing to check for design faults during the system development phase

Testing

- Testing is mainly used to find physical defects introduces during the manufacturing and operation phases
- It is an expensive and complex task. Moreover, it is becoming further difficult with the advent of much more complex systems
- Testability must be taken into account at all stages of the design process. Particularly, early testability consideration prevents costly design iterations
- The key to successful testing lies in the design process!

Tolerances

Engineering tolerance is the permissible limit of variation in:

1. A physical dimension
2. A measured value or physical property of a material, manufactured object, system, or service
3. Other measured values (such as temperature, humidity, etc.)
4. In engineering and safety, a physical distance or space (tolerance)

Assignment

- Pick up a product that you own or use or consume
- Describe its DFM as you understand or imagine it, going as far upstream as possible to raw materials
  - Where and how was it made?
  - Were the components used to make it seem appropriate?
  - Were the appropriate raw materials used?
- What do you imagine are the key challenges in planning an efficient DFM?

Introduction to 6-Sigma Concepts

How can we obtain the following results?

- Only 13 wrong drug prescriptions per year
- Only 10 newborn babies dropped by the doctors/nurses per year
- Only Two short or long landings per year in all the major airports around the world
- Only one lost letter from mail per hour

Six-Sigma: Focuses on understanding and reducing variation in processes

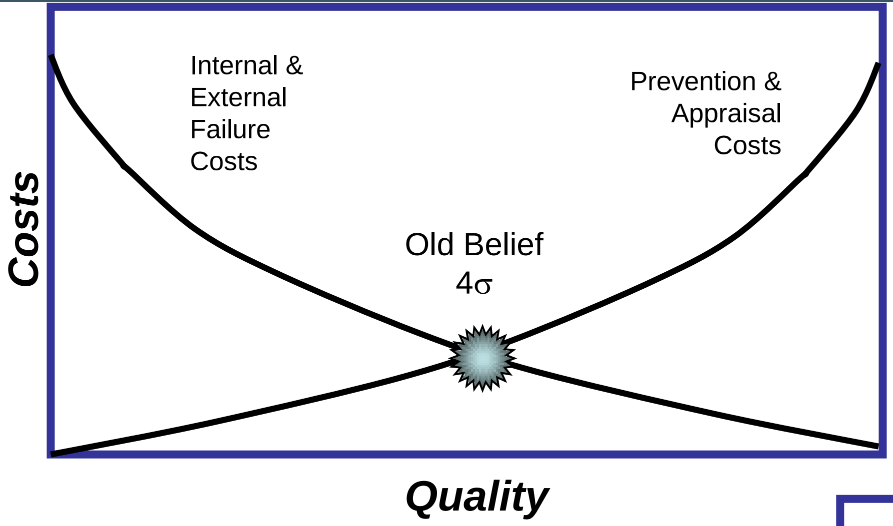
History – Evolution of Quality

- Craft production
  - Each item is unique
  - Individual parts made to fit
  - *Quality through craftsmanship*
- Mass production
  - High volume
  - Interchangeable parts
  - *Quality through inspection*
- Better production
  - Understanding of process variation
  - *Quality through process*

Evolution of Quality - Timeline

1798	1920s	1950	1960	1980
Interchangeable Parts	Statistical Process Control	Reconstruction of Japan	Toyoda Production System	Six-Sigma
Eli Whitney	**Walter Shewhart**	**Deming & Juran**	**Eiji Toyoda**	**Motorola**

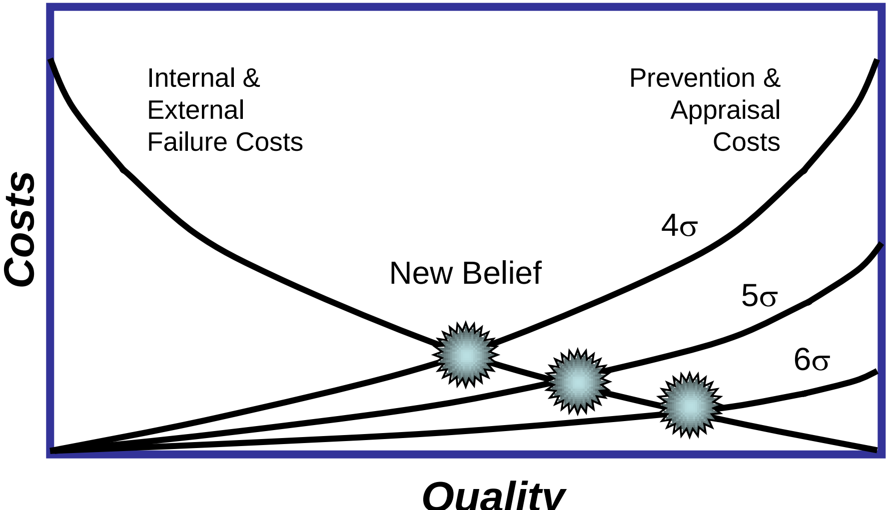
Six-Sigma Philosophy



σ is a measure of how much variation exists in a process

Old Belief

High Quality = High Cost



New Belief

High Quality = Low Cost

Better Processes Reduce Cost

How Good is Good Enough?

3 Sigma
93.3193% Accurate

- **133,600** lost letters per hour
- **33,400** incorrect surgical operations per week
- **13** short or long landings at most major airports each day
- **1,336,000** wrong prescriptions each year

4 Sigma
99.379% Accurate

- **12,420** lost letters per hour
- **3,100** incorrect surgical operations per week
- **1** short or long landing at most major airports each day
- **124,200** wrong prescriptions each year

5 Sigma
99.9767% Accurate

- **466** lost letters per hour
- **117** incorrect surgical operations per week
- **17** short or long landings every year at most major airports
- **4,660** wrong prescriptions each year

6 Sigma
99.99966% Accurate

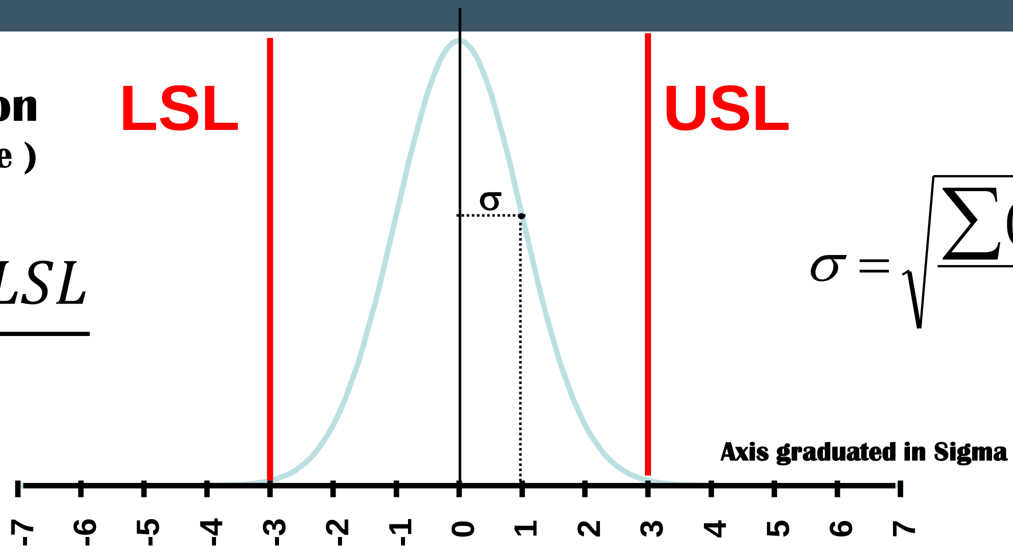
- **6.8** lost letters per hour
- **1.7** incorrect surgical operations per week
- **1** short or long landing every 5 years at most major airports
- **68** wrong prescriptions each year

Why 6-Sigma? Process Centred and Capable

University of Glasgow

Sigma = σ = **Deviation**
(Square root of variance)

$$Cp = \frac{USL - LSL}{6.\sigma}$$



$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

between + / - 1σ	68.27 %	result: 317300 ppm outside (deviation)
between + / - 2σ	95.45 %	45500 ppm
between + / - 3σ	99.73 %	2700 ppm
between + / - 4σ	99.9937 %	63 ppm
between + / - 5σ	99.999943 %	0.57 ppm
between + / - 6σ	99.9999998 %	0.002 ppm

Cp = 1 if USL – LSL = 6 σ

Process Yield: Assuming 1.5 sigma shift

Long Term Sigma (Z_{lt})	Yield	DPMO
1σ	30.85%	691,463
2σ	69.15%	308,538
3σ	93.32%	66,807
4σ	99.38%	6,210
5σ	99.977%	233
6σ	99.99966%	3.4

Table: Sigma Conversion Tab

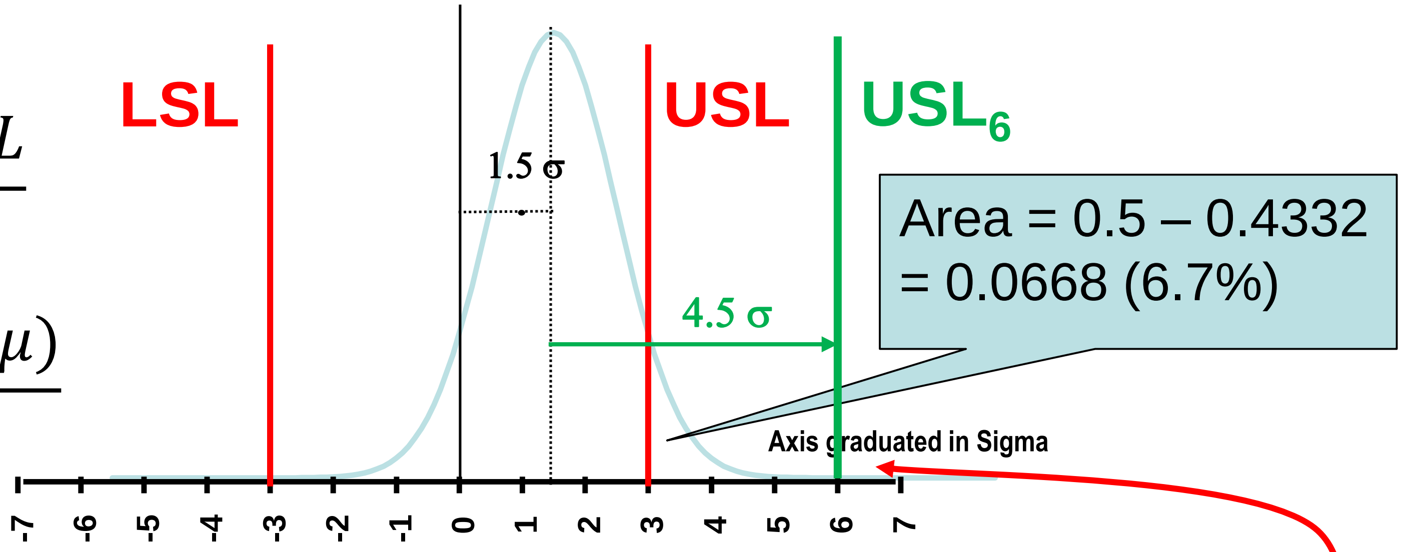
DPMO – Defects per million opportunities if mean shifts +/- 1.5 σ

Note: Yield ASSUMES 1.5 sigma shift in mean.

Why 6-Sigma? Process NOT Centred but Capable

$$Cp = \frac{USL - LSL}{6.\sigma}$$

$$Cpk = \frac{(USL^* - \mu)}{3\sigma}$$



Example calculation for 6 σ

If process mean shifted +1.5 σ then USL_6 **still** 4.5 σ away from mean (z=0)

Therefore Area = 0.5 – 0.4999966 = 3.4ppm*

* Note: *Cpk* takes the **closest** limit (could be LSL OR USL)

Six Sigma Problem Solving Approach

1. Define
2. Measure
3. Analyse
4. Improve
5. Control

DMAIC

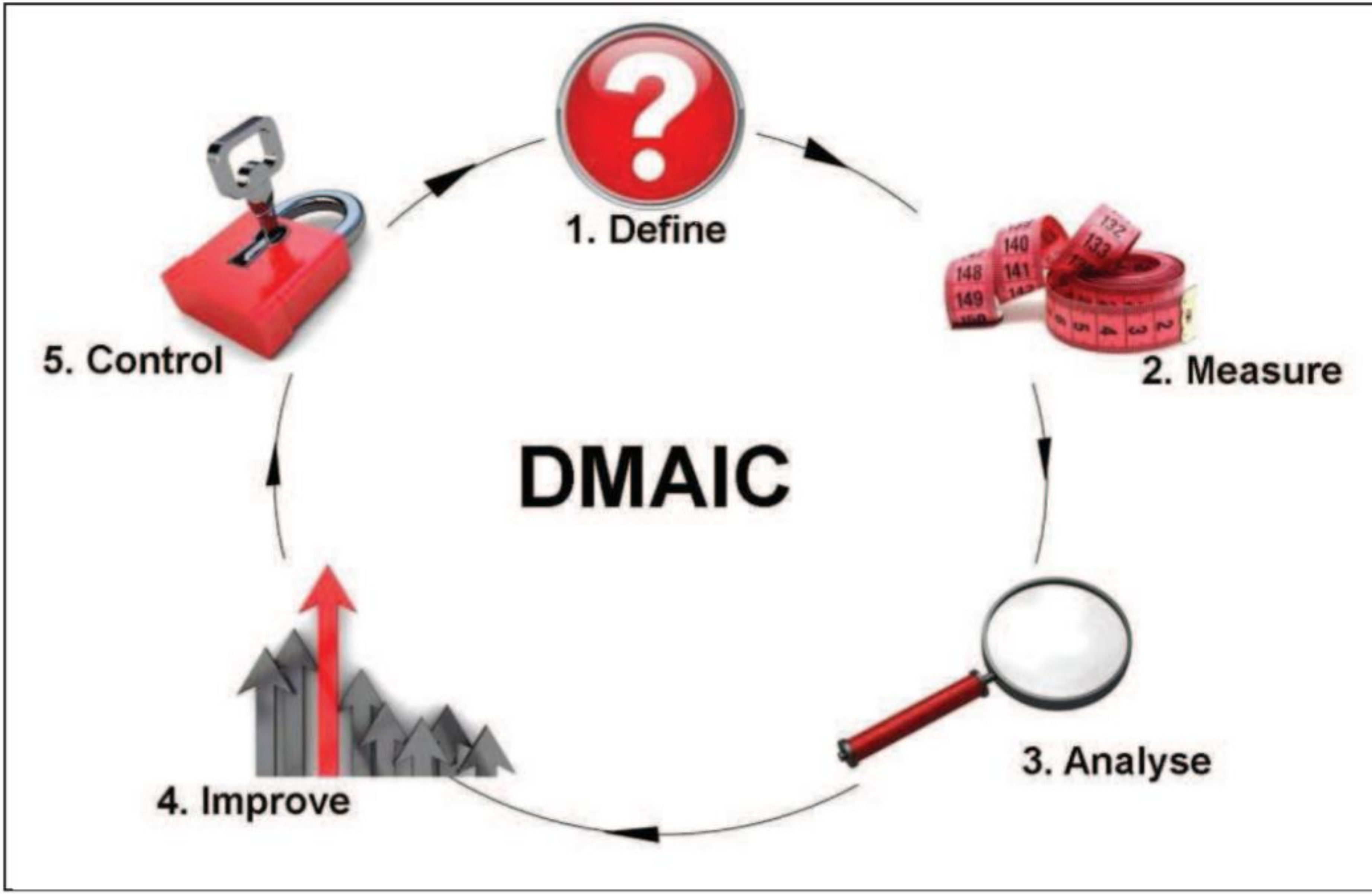


Figure: DMAIC Improvement Model

DMAIC Process

Define
- What is the problem?
- What is the goal?

Measure
- What is the current performance?
- What is the defect rate?

Analyse
- What are the sources of process variation?
- What are the root causes of defects?

Improve
- How do we change the process?
- How do we verify our changes will improve the process?

Control
- Are the improvements to the process consistent over time?
- How do we maintain the improvement into the future?

DMAIC - Define

- Identify customers and their priorities
- Identify business objectives
- Select a six sigma project team
- Define the critical-to-quality (CTQ) characteristics that the customers consider to have the most impact on quality

DMAIC - Measure

- Determine how to measure the processes
- Identify key internal processes that influence CTQs
- Measure the defect rates currently generated relative to those processes

DMAIC - Analyse

- Determine the most likely causes of defects
- Identify key factors that are most likely to create process variation

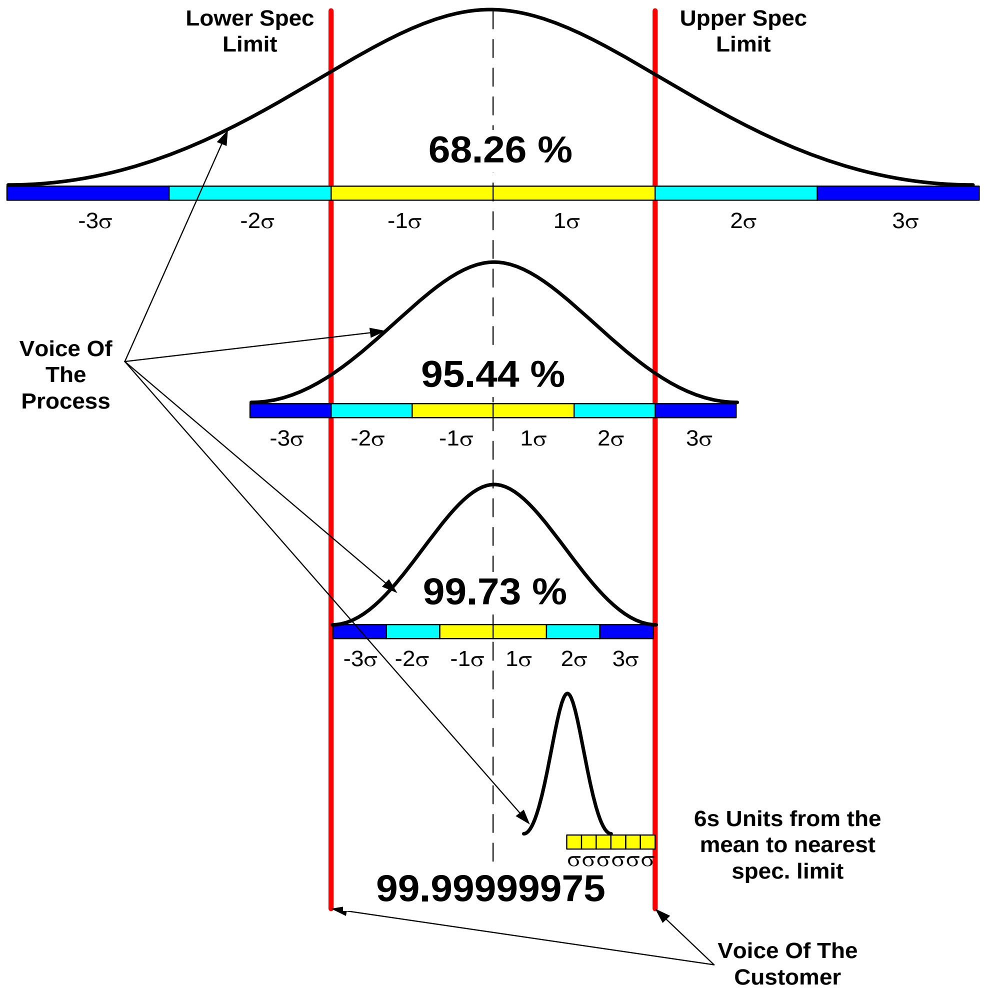
DMAIC - Improve

- Identify means to remove causes of defects
- Confirm the key variables and quantify the effects on CTQs
- Identify maximum acceptable ranges for the key variables and a system to measure deviations of the variable
- Modify the process to stay within the acceptable ranges

DMAIC - Control

- Determine how to maintain the improvement
- Put tools in place to ensure that the key variables remain within the maximum acceptable ranges under the modified process

Why 6-Sigma?

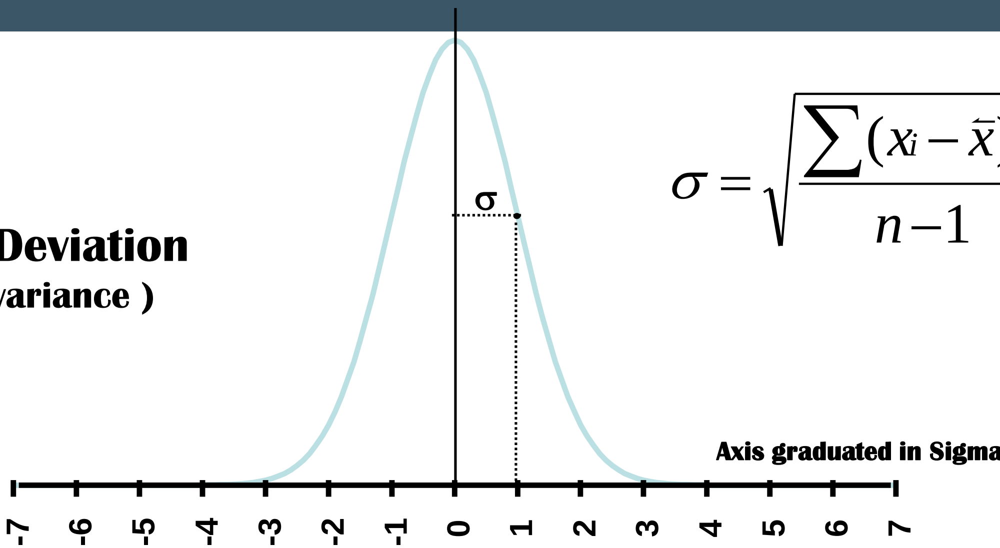


Lower Spec Limit
Upper Spec Limit
68.26 %
-3σ -2σ -1σ 1σ 2σ 3σ
Voice Of The Process
95.44 %
-3σ -2σ -1σ 1σ 2σ 3σ
99.73 %
-3σ -2σ -1σ 1σ 2σ 3σ
σσσσσσ
6s Units from the mean to nearest spec. limit
99.99999975
Voice Of The Customer

Why 6-Sigma?

Sigma = σ = Deviation
(Square root of variance)

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$



between + / - 1σ	68.27 %	result: 317300 ppm outside (deviation)
between + / - 2σ	95.45 %	45500 ppm
between + / - 3σ	99.73 %	2700 ppm
between + / - 4σ	99.9937 %	63 ppm
between + / - 5σ	99.999943 %	0.57 ppm
between + / - 6σ	99.9999998 %	0.002 ppm

Conclusion

- Design for Manufacturing (DFM)
  - Challenges
  - Sources
  - Assembly
  - Testing
  - Tolerances
- 6-Sigma concepts
  - How good is good enough?
  - DMAIC

References

- *The New Economics*: W. Edwards Deming
- *Understanding Statistical Process Control*: Donald J. Wheeler and David S. Chambers

Post Lecture X Reading Material

Read the following:

- A Survey of Current Challenges in Manufacturing Industry and Preparation for Industry 4.0; 2016

Skim | Read | Understand | Critique