Module V

Expediency, Economics and Environment in Design Engineering

Contents

- Expediency, Economics and Environment in Design Engineering:-
  - Design for Production, Use, and Sustainability.
  - Engineering Economics in Design.
  - Design Rights.
  - Ethics in Design.

Design for "X"

- Engineers always try to realize various desirable attributes to some degree in their designs, embodied in the design process as objectives.
- This is often referred to as "design for X," where X is an attribute such as
  - Manufacturability
  - Maintainability
  - Reliability
  - Affordability
  - Assembly/Fitting
  - Disassembly and Recycling
  - Safety
- These are some factors to be considered in the design to make it competitive in the market.

DESIGN FOR PRODUCTION :

- Design for manufacturing (DFM)
- Design for Assembly (DFA)
- The Bill of Materials and Production

CAN THIS DESIGN BE MADE?

Design for manufacturing (DFM)

- Design for manufacturing (DFM) is design based on minimizing the costs of production and/or the time to market for a product, while maintaining an appropriate level of quality.
- Design for manufacturing (DFM) is a development practice emphasizing manufacturing issues throughout the product development process.
- Successful DFM results in lower production cost without sacrificing product quality.
- DFM begins with the formation of the design team.
  - Multidisciplinary

- DFM utilizes information of several types
  - Sketches, drawings, product specifications, and design alternatives;
  - A detailed understanding of production and assembly processes;
  - Estimates of manufacturing costs, production volumes, and ramp-up timing.
- DFM Is Performed throughout the Development Process

Major DFM objectives

- Reduce component costs
- Reduce assembly cost
- Reduce production support costs

The design for manufacturing (DFM) method

1. Estimate the manufacturing costs for a given design alternative
2. Reduce the costs of components
3. Reduce the costs of assembly
4. Reduce the costs of supporting production
5. Consider the effects of DFM on other objectives
6. If the results are not acceptable, revise the design once again.

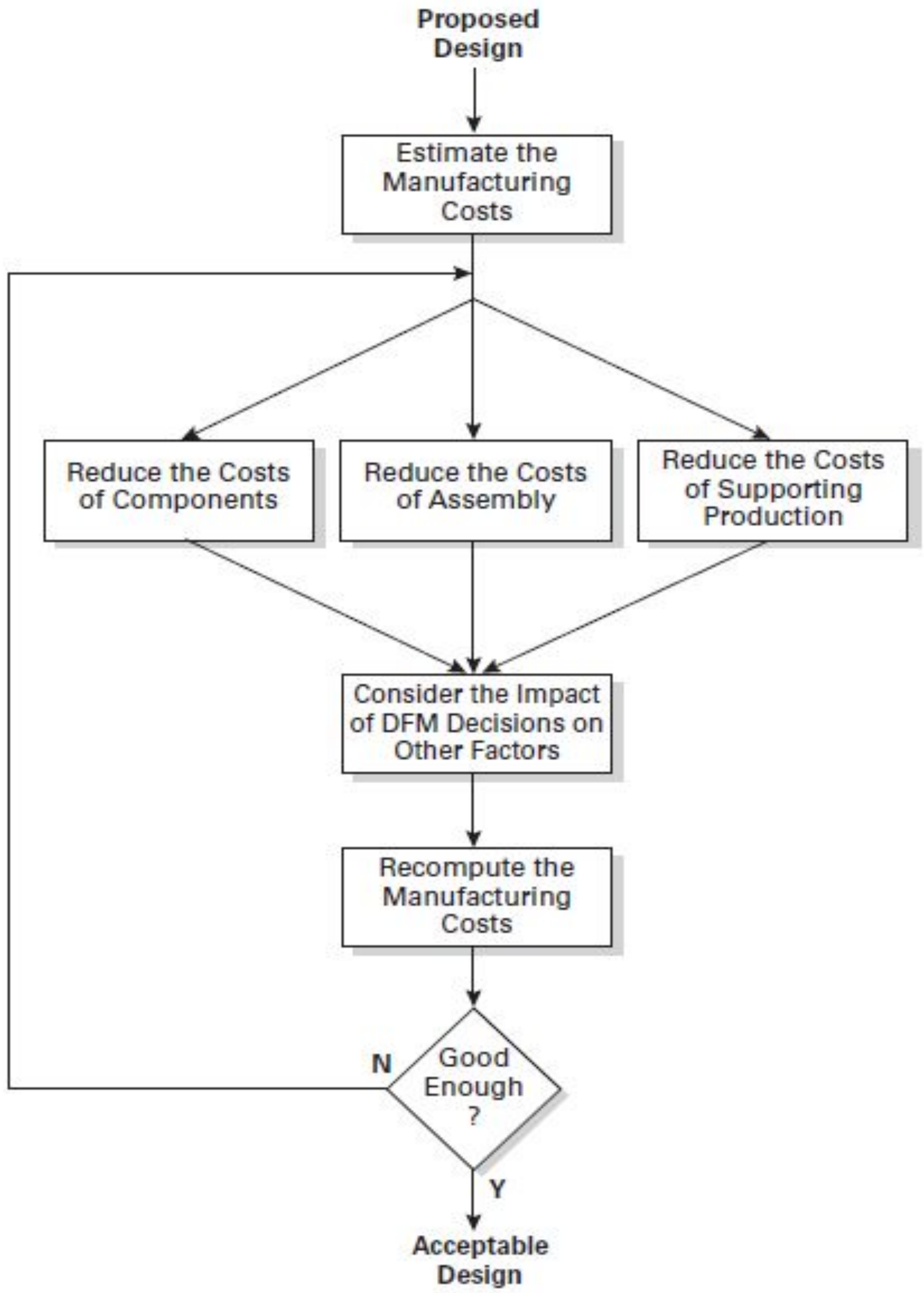
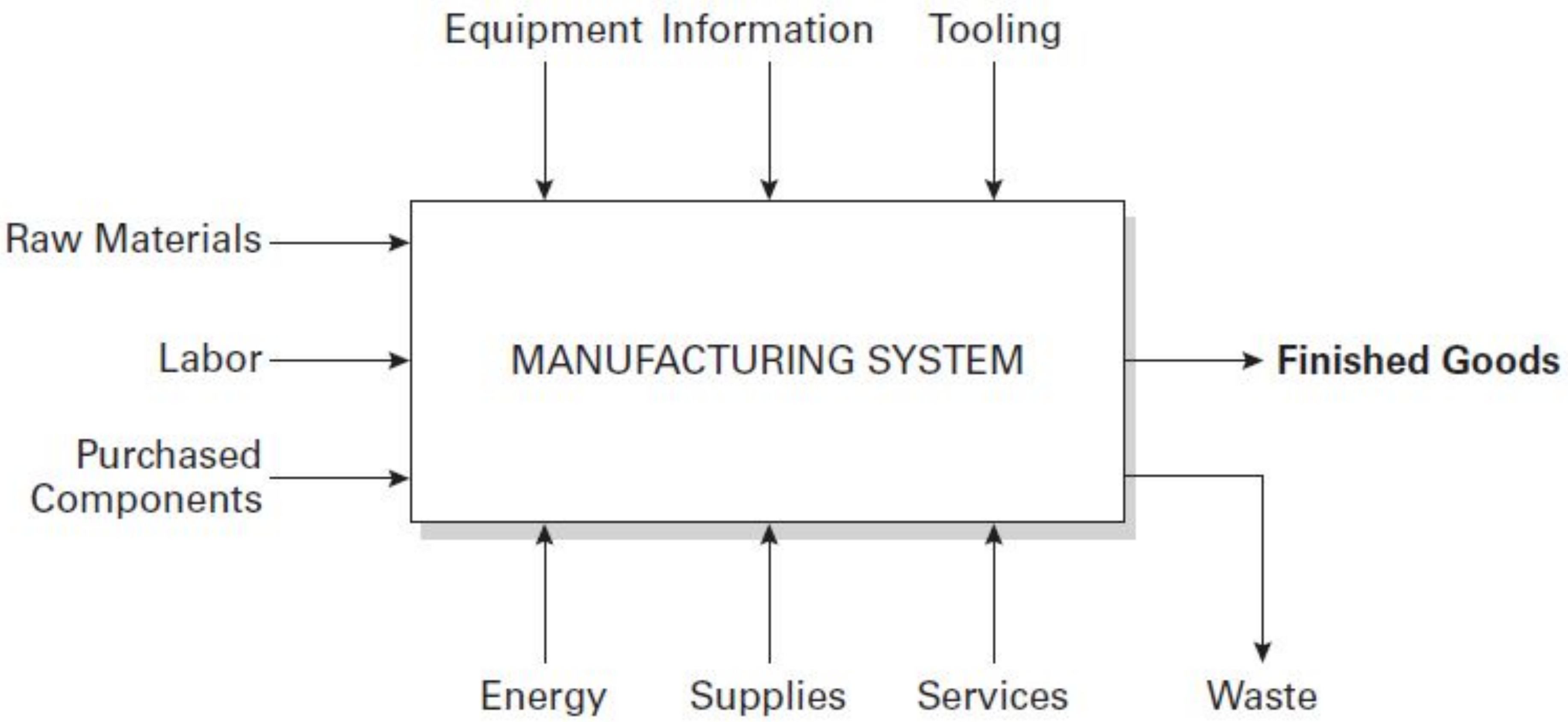


EXHIBIT 13-4
A simple input-output model of a manufacturing system.



1. Estimate the manufacturing costs

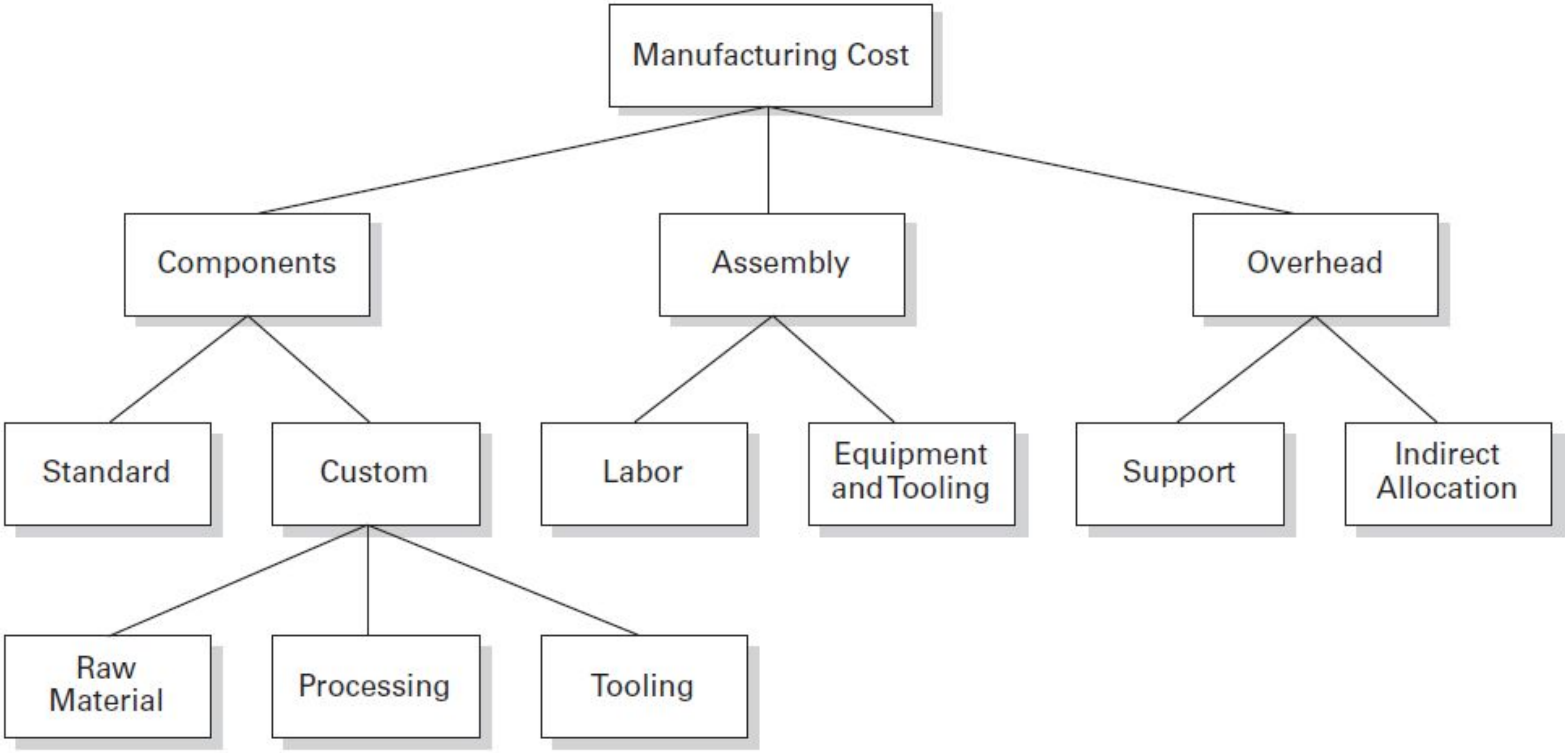


EXHIBIT 13-5 Elements of the manufacturing cost of a product.

1. Estimate the manufacturing costs

- Cost categories
  - Component vs. assembly vs. overhead
  - Fixed vs. variable
  - Material vs. labor
- Estimate costs for standard parts
  - Compare to similar part in use
  - Get a quote from vendors
- Estimate costs of custom made parts
  - Consider material costs, labor costs, and tooling costs
  - Depend on the production volume as well
- Estimate costs of assembly
  - Summing up all assembly operations (time by rate)
- Estimate the overhead costs
  - A % of the cost drives

2. Reduce the costs of components

- Identify process constraints and cost drivers
- Redesign components to eliminate processing steps
- Choose the appropriate economic scale for the part process
- Standardize components and their processes
- Adhere the black-box component

3. Reduce the costs of assembly

- Integrate parts
- Maximize 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 (do-it-yourself) technology driven products

4. Reduce the costs of supporting production

- Minimize systematic complexity
  - An extremely simple manufacturing system would utilize a single process to transform a single raw material into a single part.
  - Unfortunately, few such systems exist.
- Error proofing (anticipate possible failure modes in the production system and take appropriate corrective actions early in the development process)

5. Considering impacts

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

Design for Assembly (DFA)

- Assembly refers to the way in which the various parts, components, and subsystems are joined, attached, or otherwise grouped together to form the final product.

- Assembly can be characterized as consisting of a set of processes by which the assembler

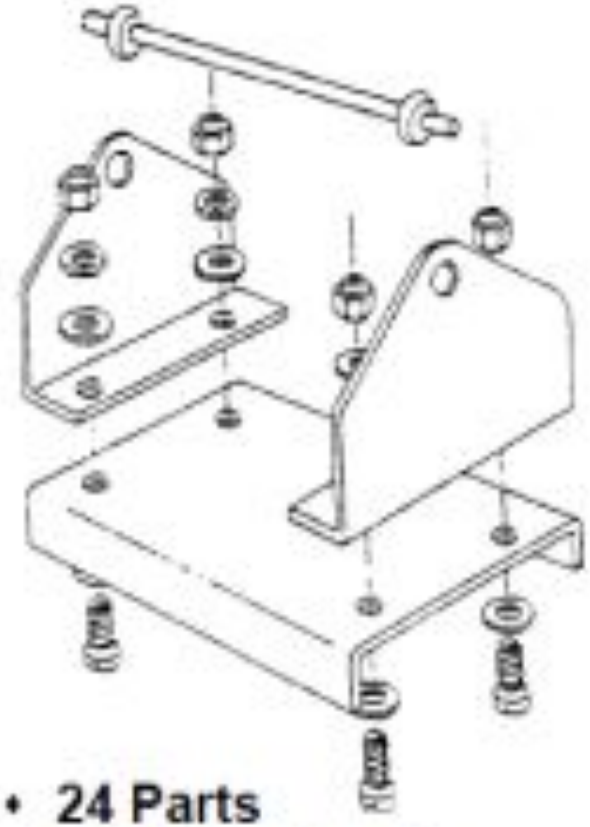
1. Handles parts or components (i.e., Retrieves and positions them appropriately relative to each other), and

2. Inserts (or mates or combines) the parts into a finished subsystem or system.

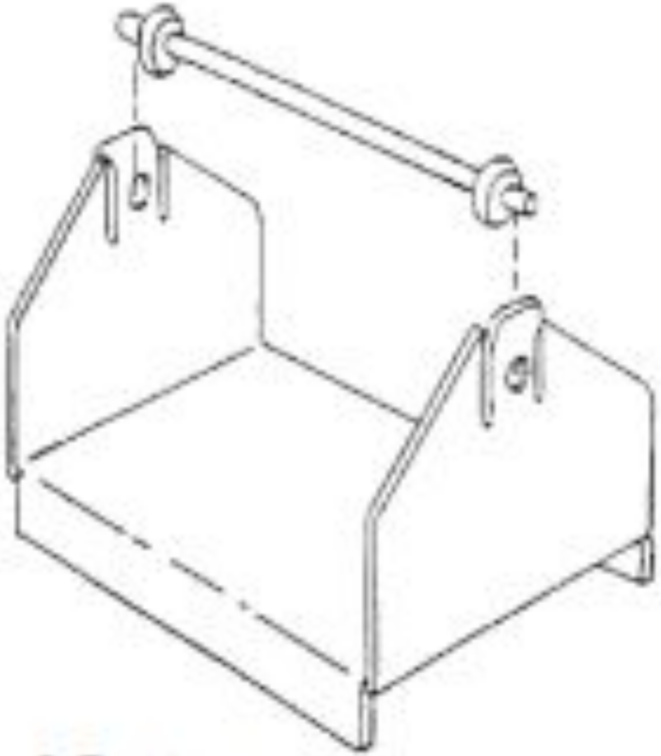
- Assembly is often the costly part in manufacture.
- Assembly automation to reduce the time and cost is not easy.
- Manual assembly is very costly.
- However by designing the product suitably many assembly operations can be automated.
- Assembly costs reduction can lower overall manufacturing costs

DFA : Guidelines

- Limiting the number of components to the fewest that are essential to the working of the finished product
- Using standard fasteners and/or integrating fasteners into the product itself
- Designing the product to have a base component on which other components can be located
- Designing the product to have components that facilitate retrieval and assembly
- Designing the product and its component parts to maximize accessibility, during both manufacturing and subsequent repair and maintenance.

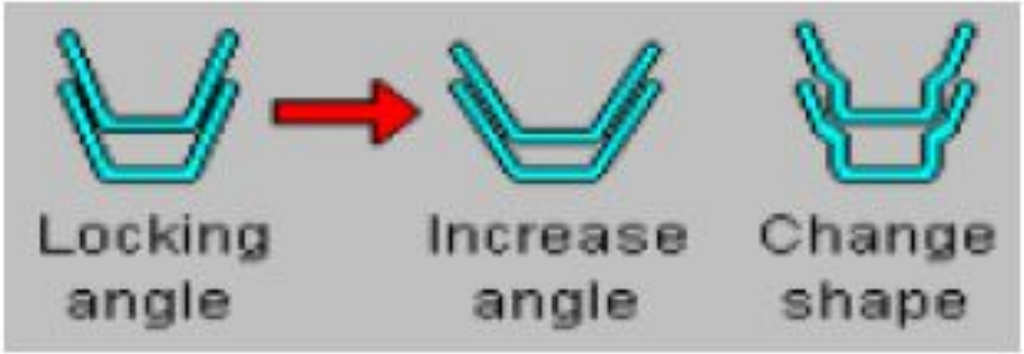


- 24 Parts
- 8 different parts
- multiple mfg. & assembly processes necessary

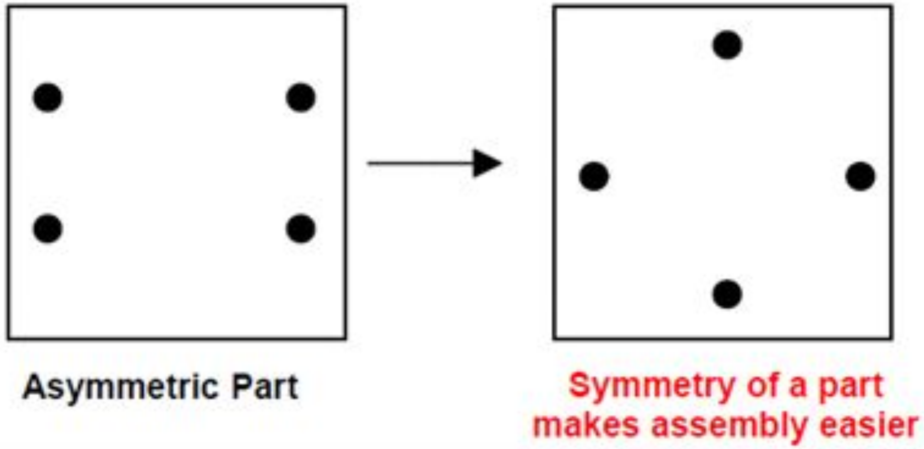


- 2 Parts
- 2 Manufacturing processes
- one assembly step

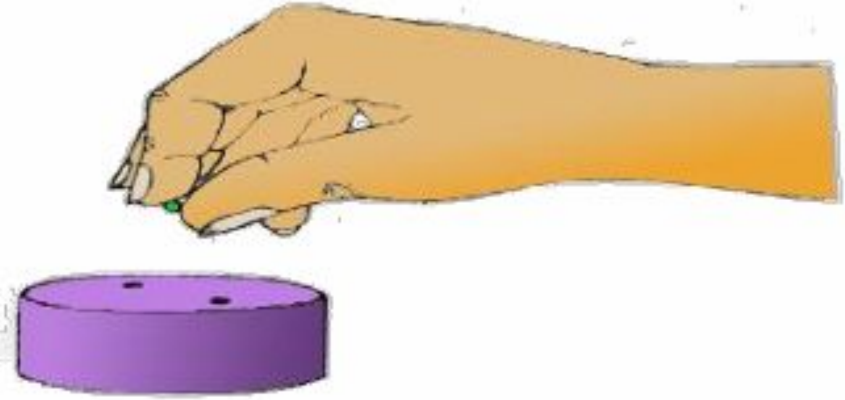
Vertical Assembly – Easy to Automate



Avoid nesting & tangling

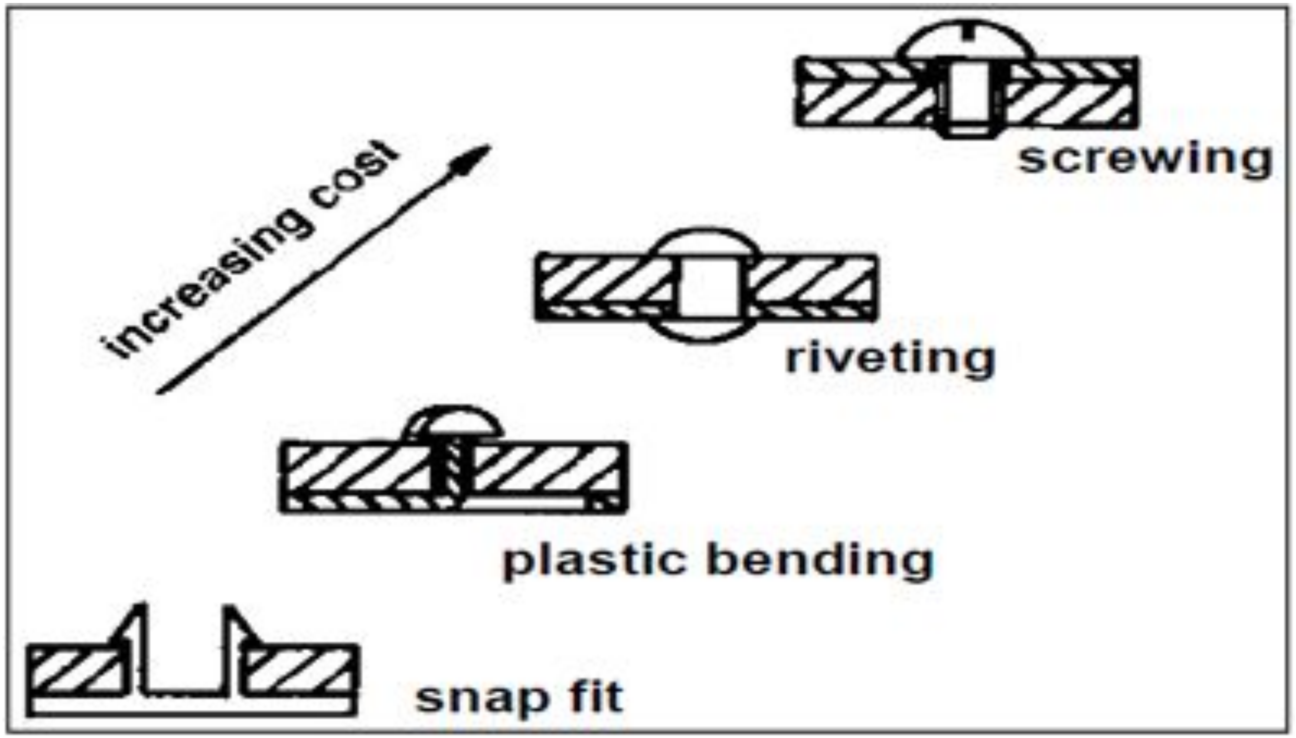


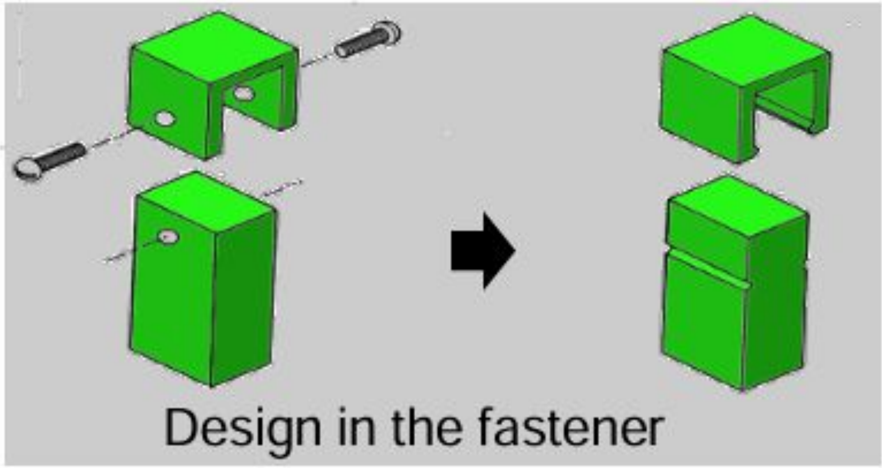
Symmetry eliminates reorientation

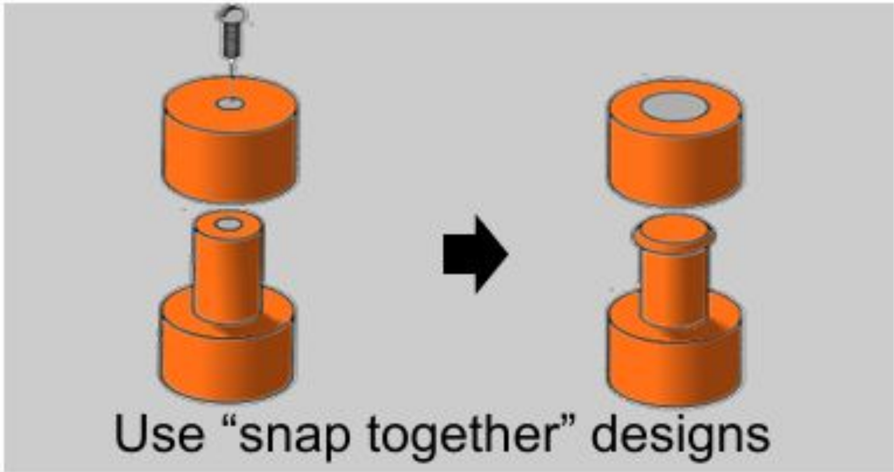


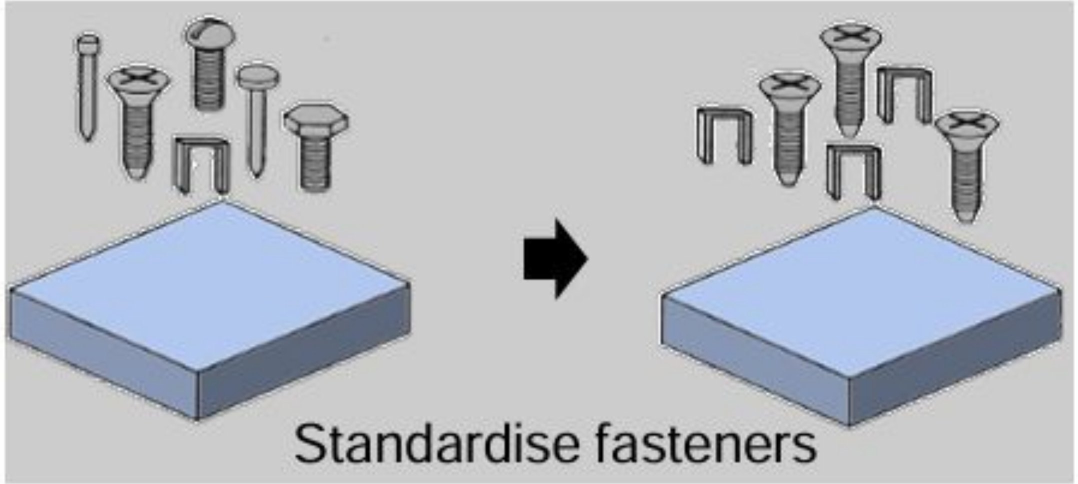
Avoid small items requiring precision placement

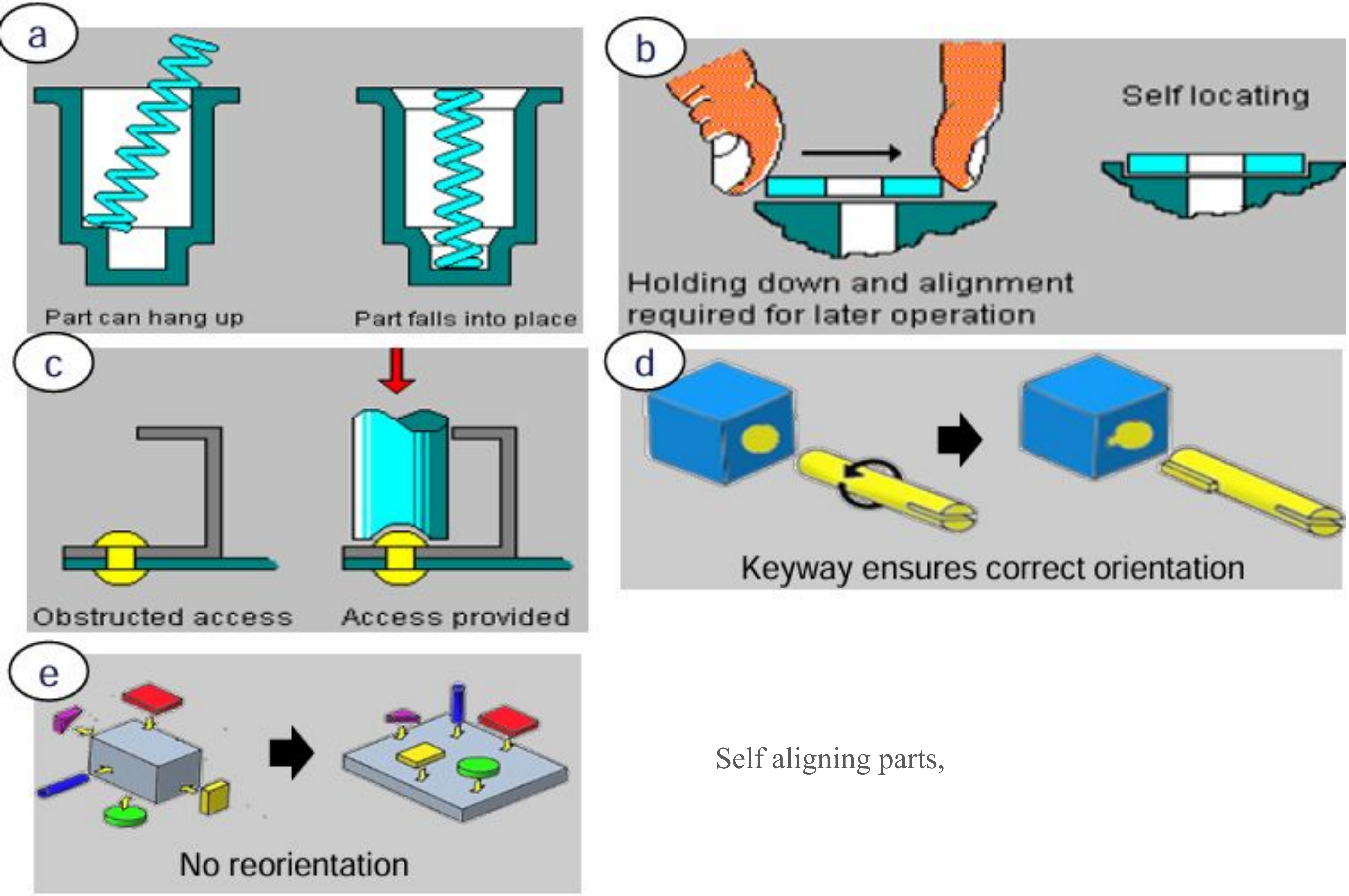
When using mechanical fasteners, attempt to use the low cost one.



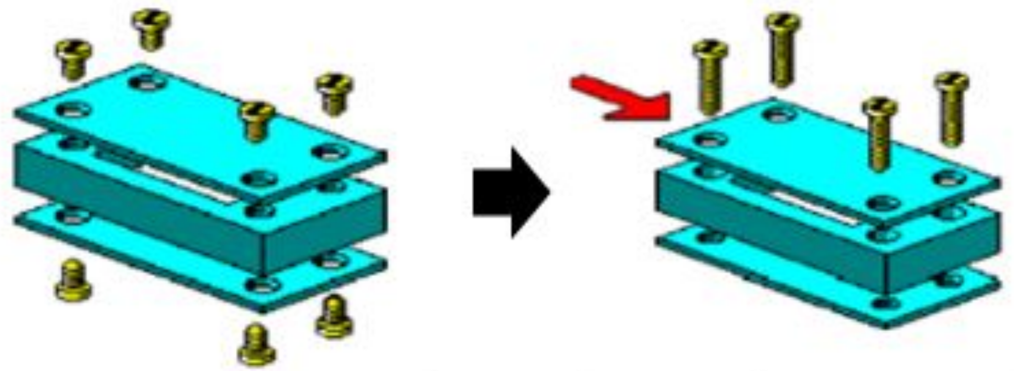




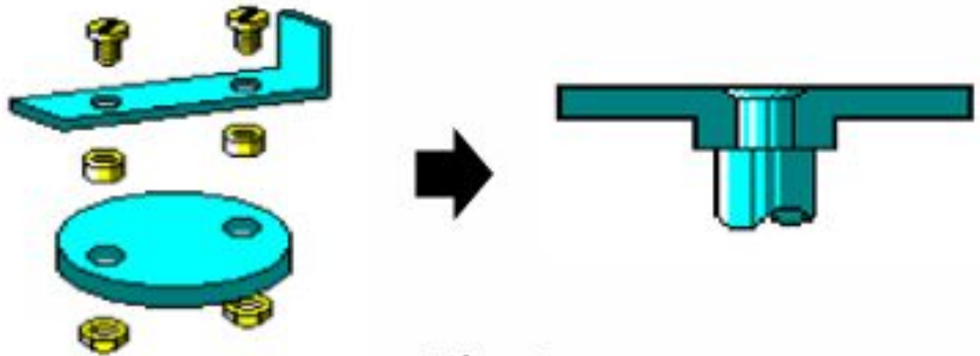




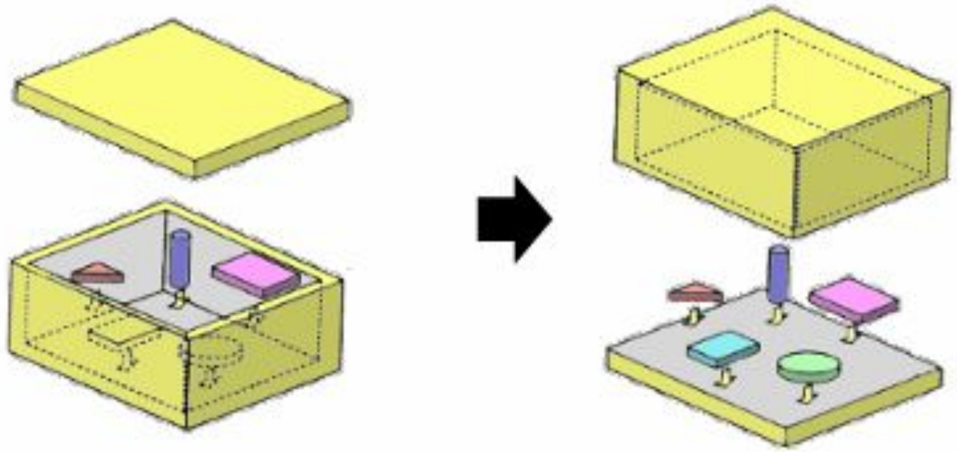
Self aligning parts,



Screw down from above



Rivet



Eliminate restricted access

Design for Assembly

- Key ideas of DFA:
  - Minimize parts count
  - Maximize the ease of handling parts
  - Maximize the ease of inserting parts
- Benefits of DFA
  - Lower labor costs
  - Other indirect benefits

Before DFA Analysis

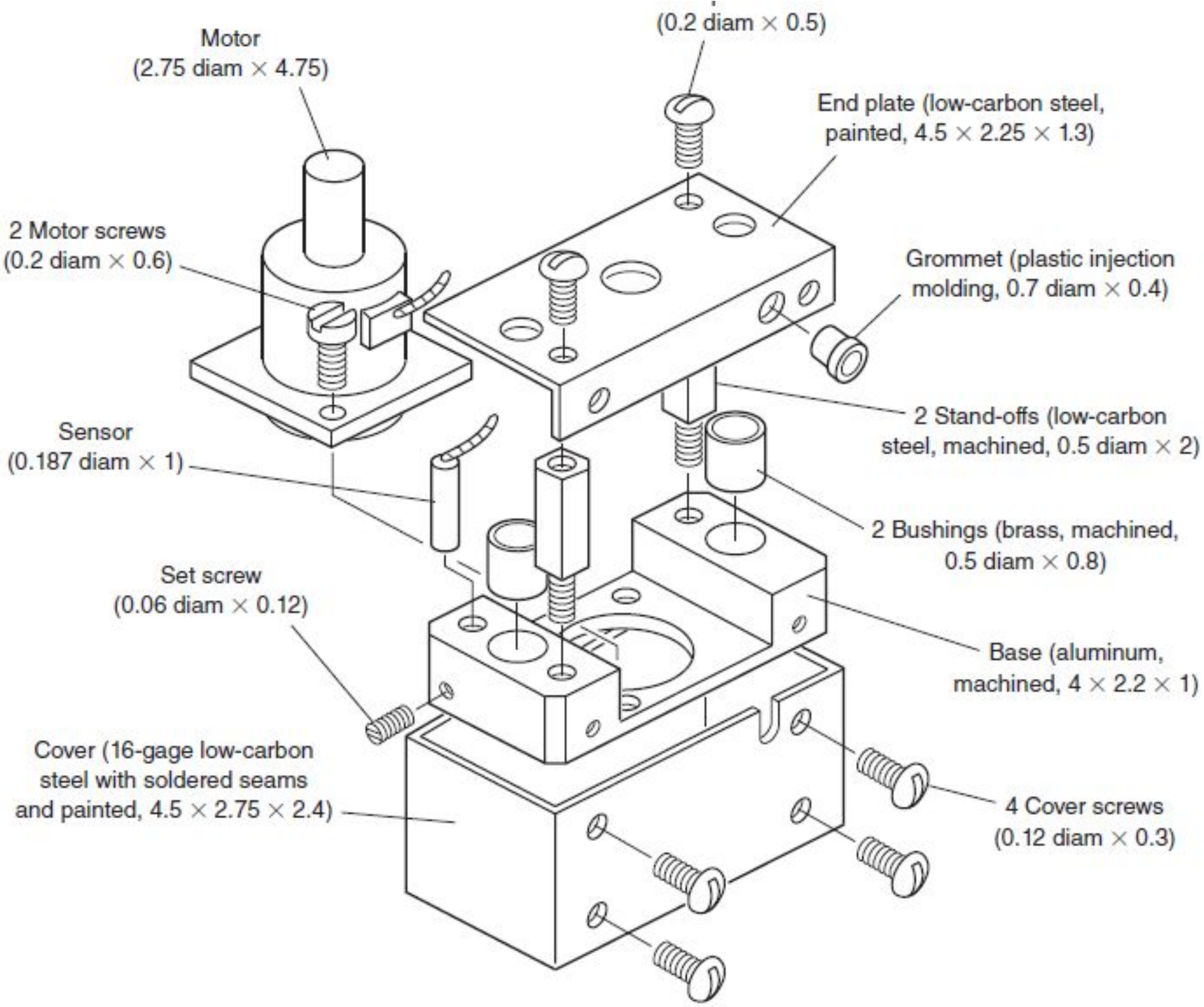


FIGURE 13.16
Initial design of the motor-drive assembly. (*ASM Handbook*, Vol. 20, p. 680, ASM International, Materials Park, OH, 1997. Used with permission.)

After DFA Analysis

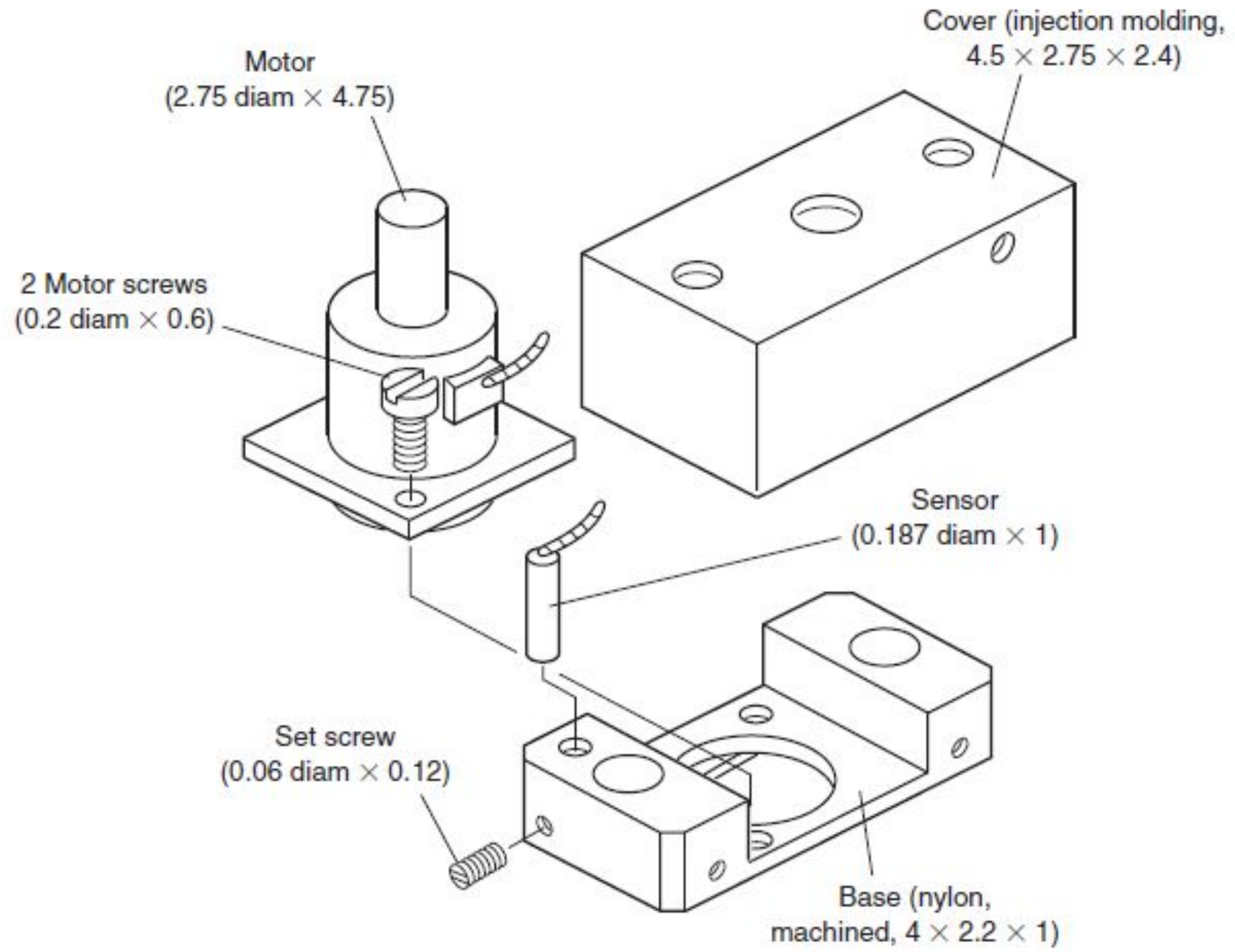


FIGURE 13.17
Redesign of motor-drive assembly based on DFA analysis. (*ASM Handbook*, Vol. 20, p. 68, ASM International, Materials Park, OH, 1997. Used with permission.)

The Bill of Materials and Production

- Materials include those items and inputs directly used in building the device, along with intermediate materials and inventories that are consumed in the manufacturing process.
- A key tool for estimating the materials cost of an artifact is the bill of materials (BOM), the list of all of the parts in our design, including the quantities of each part required for complete assembly.
- Effective design for manufacturing and assembly requires a deep understanding of production processes
  - Ways to plan and
  - Control inventories.

The Bill of Materials and Production

- A common inventory planning technique is materials requirements planning (MRP).
- It utilizes assembly drawings to develop a bill of materials (BOM) and an assembly chart that shows the order in which the parts on the BOM are put together.
- Manufacturing concerns include both logistics and distribution, so that these elements have also become an important part of design for manufacturing and assembly.

- The following information should be included in a bill of material.

1. *The item number:* This is a key to the components on the assembly drawing.
2. *The part number:* This is a number used throughout the purchasing, manufacturing, and assembly system to identify the component. The item number is a specific index to the assembly drawing; the part number is an index to the company system.
3. *The quantity needed in the assembly*.
4. *The name and description of the component*.
5. *The material from which the component is made*.
6. *The source of the component*.
7. *The cost of the individual component:* This part will be kept for the design team.

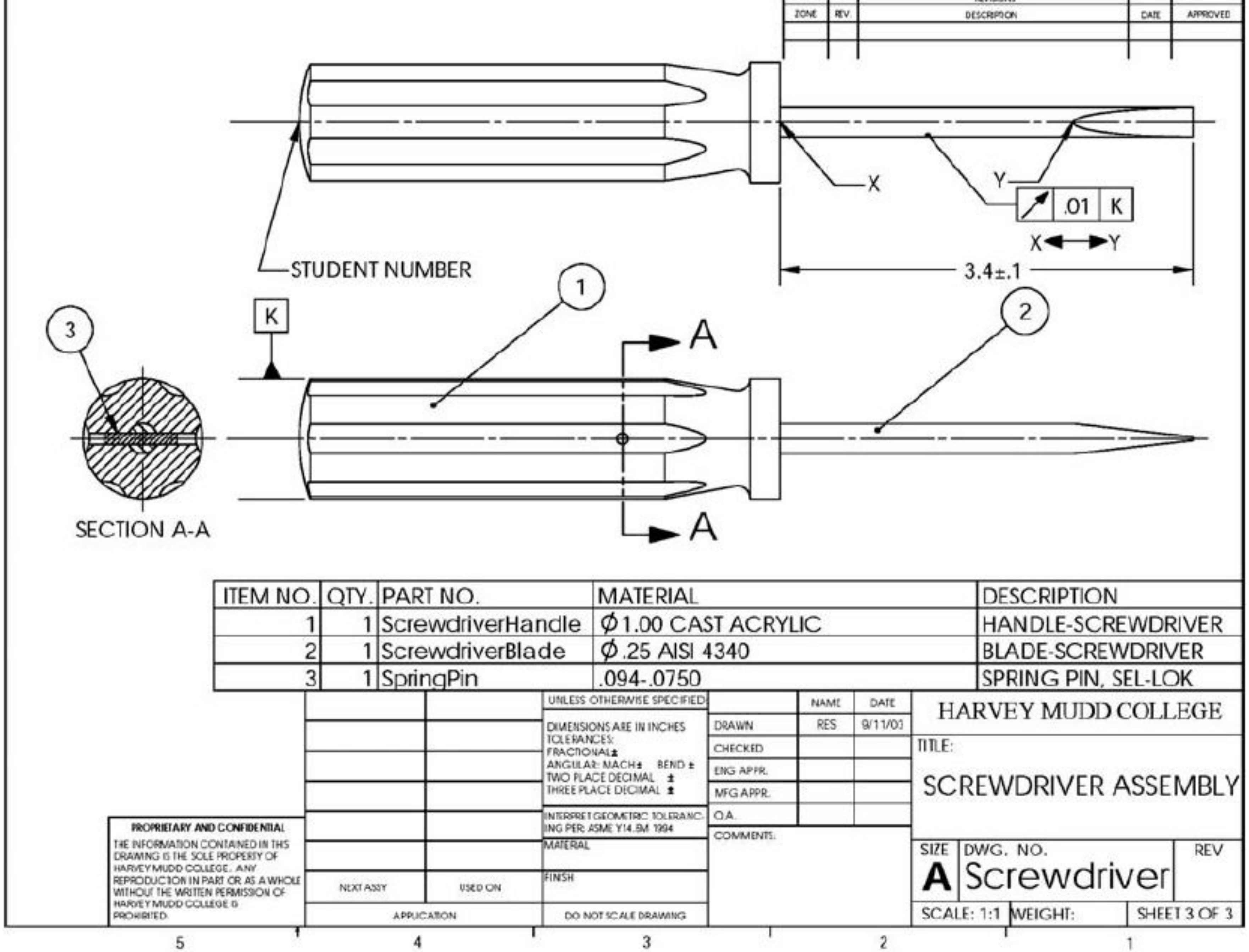


Figure 13.1 The bill of materials (BOM) for a screwdriver, listing all of the materials needed to fabricate the part. In this case, the BOM is built into a drawing, but it could be given as a separate list. (Drawing courtesy of R. Erik Spjut.)

Bill of Materials

Item	Part	Quantity	Name	Material	Source
1	G-9042-1	1	Governer body	Cast aluminum	Lowe's
2	G-9138-3	1	Governer flange	Cast aluminum	Lowe's
9	X-1784	4	Governer bolt	Plated steel	Fred's Fine Foundry

DESIGN FOR USE:

- Design for use ties together the designer–client–user triangle in a powerful way.
- User Friendly
- Reliability
- Maintainability

HOW LONG WILL THIS DESIGN WORK?

Reliability

- Reliability is defined as “the probability that an item will perform its function under stated conditions of use and maintenance for a stated measure of a variate (time, distance, etc.).
  - We can properly measure the reliability of a component or system only under the assumption that it has been or will be used under some specified conditions.
  - The appropriate measure of use of the design, called the variate, may be something other than time.
  - We must examine reliability in the context of the functions , which emphasizes the care we should take in developing and defining the functions that a design must perform.
  - Reliability is treated as a probability.

Reliability

- In practice, we consider reliability in the context of the opposite of success, that is, in terms of failure.
- It is useful to distinguish between when a system fails and how it fails
  - If the item fails when in use, the failure can be characterized as an in-service failure.
  - If the item fails, but the consequences are not detectable until some other activity takes place, we refer to that as an incidental failure.
  - A catastrophic failure occurs when a failure of some function is such that the entire system in which the item is embedded fails.

- We often specify reliability by using measures such as the mean time between failures (MTBF), or miles per in-service failure, or some other metric.

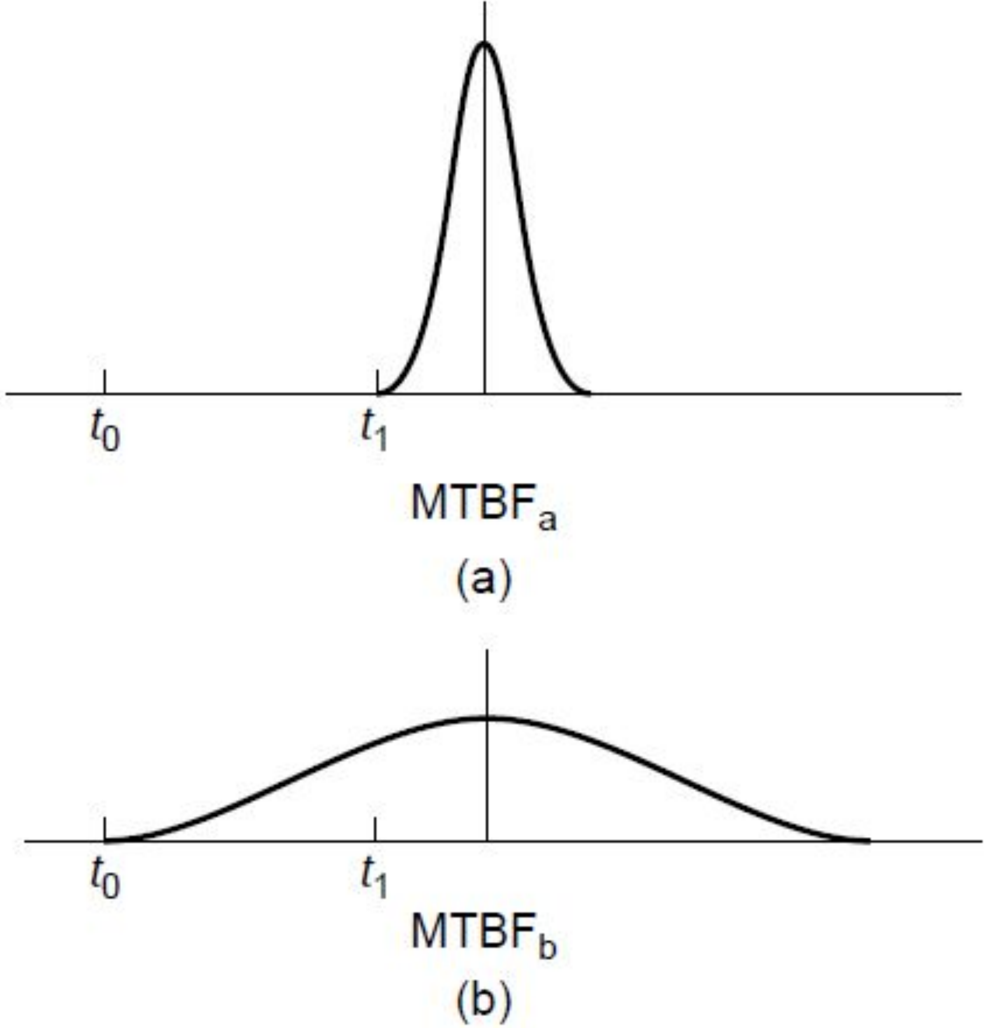


Figure 14.1 Failure distributions (also called probability density functions) for two different components. Note that both curves have the same value of MTBF, but that the dispersions of possible failures differ markedly. The second design (b) would be viewed as less reliable because more failures would during the early life of the component (i.e., during the time interval $t_0 \leq t \leq t_1$).

- One of the most important reliability issues for a designer is how the various parts of the design come together and what the impact is likely to be if any one part does fail.

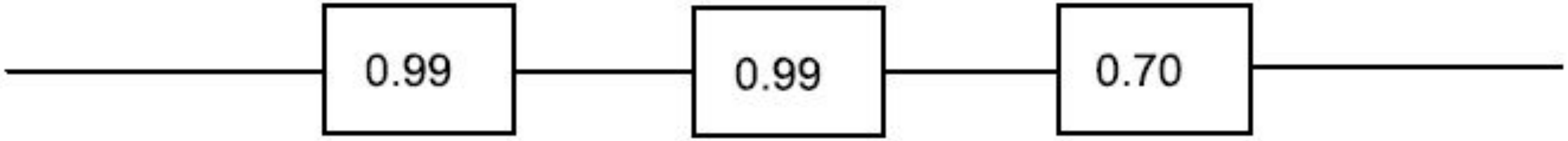


Figure 14.2 This is a simple example of a *series system*. Each of the elements in the system has a given reliability. The reliability of the system as a whole can be no higher than that of any one of the parts because the failure of any one part will cause the system to cease operating.

$$R_S(t) = R_1(t) \cdot R_2(t) \cdot \cdots \cdot R_n(t)$$

$$R_S(t) = \prod_{i=1}^{n} R_i(t)$$

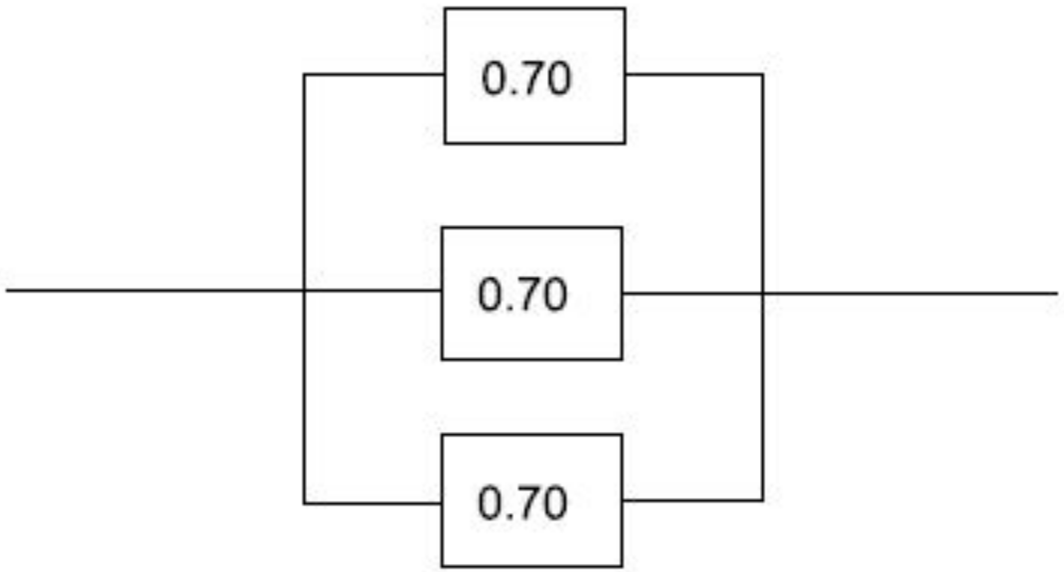


Figure 14.3 This is a simple example of a *parallel system*. Note that every one of the components must fail in order for the system to cease working. While such a system has high reliability, it is also quite expensive. Most designers seek to incorporate such redundancy when necessary, but look for other solutions wherever possible.

$$R_P(t) = 1 - [(1 - R_1(t)) \cdot (1 - R_2(t)) \cdot \cdots \cdot (1 - R_n(t))]$$

or

$$R_P(t) = 1 - \prod_{i=1}^{n} [1 - R_i(t)]$$

Specific steps to design for reliability

- Inadequate design
  - Can be addressed in part by material selection
- Manufacturing defects
  - Are best resolved by giving attention to DFM
- Use-related failures

Maintainability

- Design things so that necessary maintenance can be performed effectively and efficiently.
- The probability that a failed component or system will be restored or repaired to a specific condition within a period of time when maintenance is performed within prescribed procedures.
- Maintainability depends upon a prior specification of the condition of the part or device and on any maintenance or repair actions.
- Maintainability is concerned with the time needed to return a failed unit to service.

How to ensure maintainability?

- Selecting parts that are easily accessed and repaired
- Providing redundancy so that systems can be operated while maintenance continues
- Specifying preventive or predictive maintenance procedures
- Indicating the number and type of spare parts that should be held in inventories in order to reduce downtime when systems fail.

Considerations that designers should bear in mind

- Fault isolation and self-diagnosis
- Part standardization and interchangeability
- Modularization and accessibility

- **Fault isolation and self-diagnosis**: It usually takes time to identify what has gone wrong with a system. As designers we can help reduce this time by building clear indicators into systems that identify the part of that system requires attention.

- **Part standardization and interchangeability**: Using standard parts in the design helps us to identify the number of parts held in inventories, and to reduce the skills needed to make repairs.

- **Modularization and accessibility**: Designs that modularize (i.e., package related components together) greatly reduce the time needed to restore a broken system to a working state, especially if the modules are themselves easy to replace. Parts with higher expected failure rates can often be placed in a system in ways that make them accessible without removal of other, functional parts.

DESIGN FOR SUSTAINABILITY

- The concept of ‘Design for Sustainability’ (D4S) requires that the design process and resulting product take into account not only environmental concerns but social and economic concerns as well.
- Environmental Issues and Design
- Global Climate Change
- Environmental Life-Cycle Assessments

WHAT ABOUT THE ENVIRONMENT?

What is Sustainability?

- One definition of sustainability:

  “An economic state where the demands placed upon the environment by people and commerce can be met without reducing the capacity of the environment to provide for future generations.”.

Your business must deliver clothing, objects, food or services to the customer in a way that reduces consumption, energy use, distribution costs, economic concentration, soil erosion, atmospheric pollution, and other forms of environmental damage.

What is Design for Sustainability?

Sustainable design (also called environmental design, environmentally sustainable design, environmentally conscious design, etc.) is the philosophy of designing physical objects, the built environment, and services to comply with the principles of economic, social, and ecological sustainability.

Approaches to Sustainable Design

- Minimize sources of environmental impacts
  - Material selection
  - Manufacturing processes
  - Energy use
- Design for Life Cycle of a product, not just the product
  - Implement guidelines that reduce impact through the life cycle of the product
- Industrial ecology
  - Circulating and using materials
  - Reducing material use
  - Protecting living organisms
  - Minimizing the use of energy

Environmental Issues and Design

- The environmental implications of a design in terms of the effects on
  - Air quality,
  - Water quality,
  - Energy consumption, and
  - Waste generation.

Global Climate Change

- Sometimes referred to as global warming
- Engineers have a special obligation to involve themselves in finding ways to address global climate change
- Carbon is emitted into the atmosphere – greenhouse gases
- Designing to reduce carbon emissions often begins with the measurement of the "**carbon footprint**".

Environmental Life-Cycle Assessments (LCA)

- Life-cycle assessment is a tool that was developed to help product designers understand, analyze, and document the full range of environmental effects of design, manufacturing, transport, sale, use, and disposal of products.
- Depending on the nature of the LCA and the product, such analysis begins with the acquisition and processing of raw materials (such as petroleum drilling and refining for plastic products, or foresting and processing of railroad ties), and continues until the product has been reused, recycled, or placed in a landfill.

Stages of the Life Cycle of Product

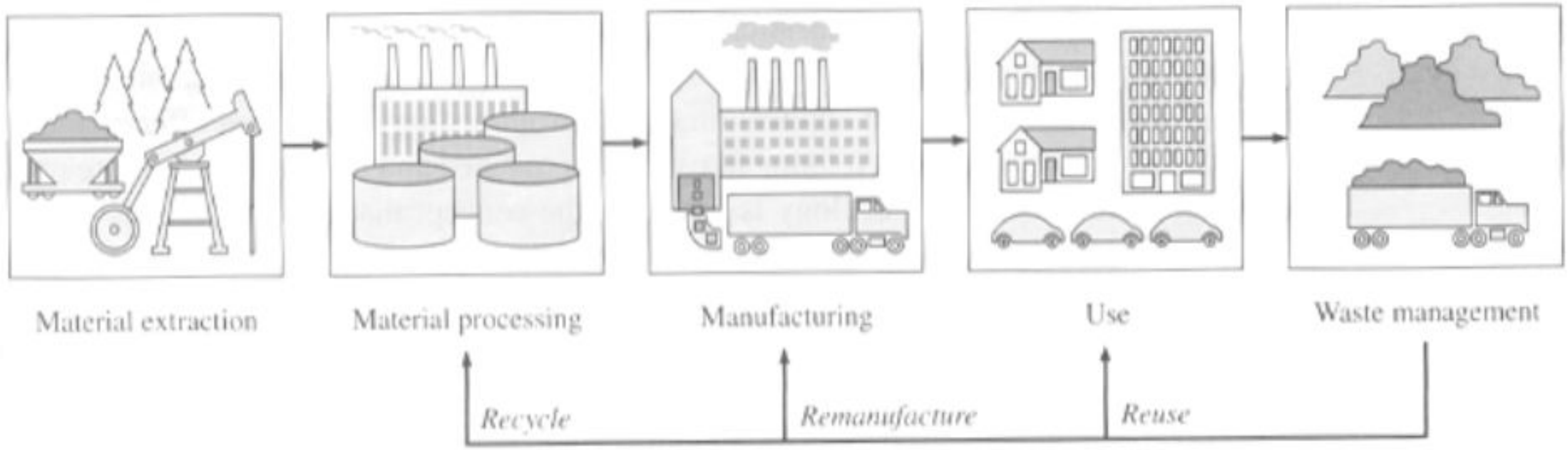
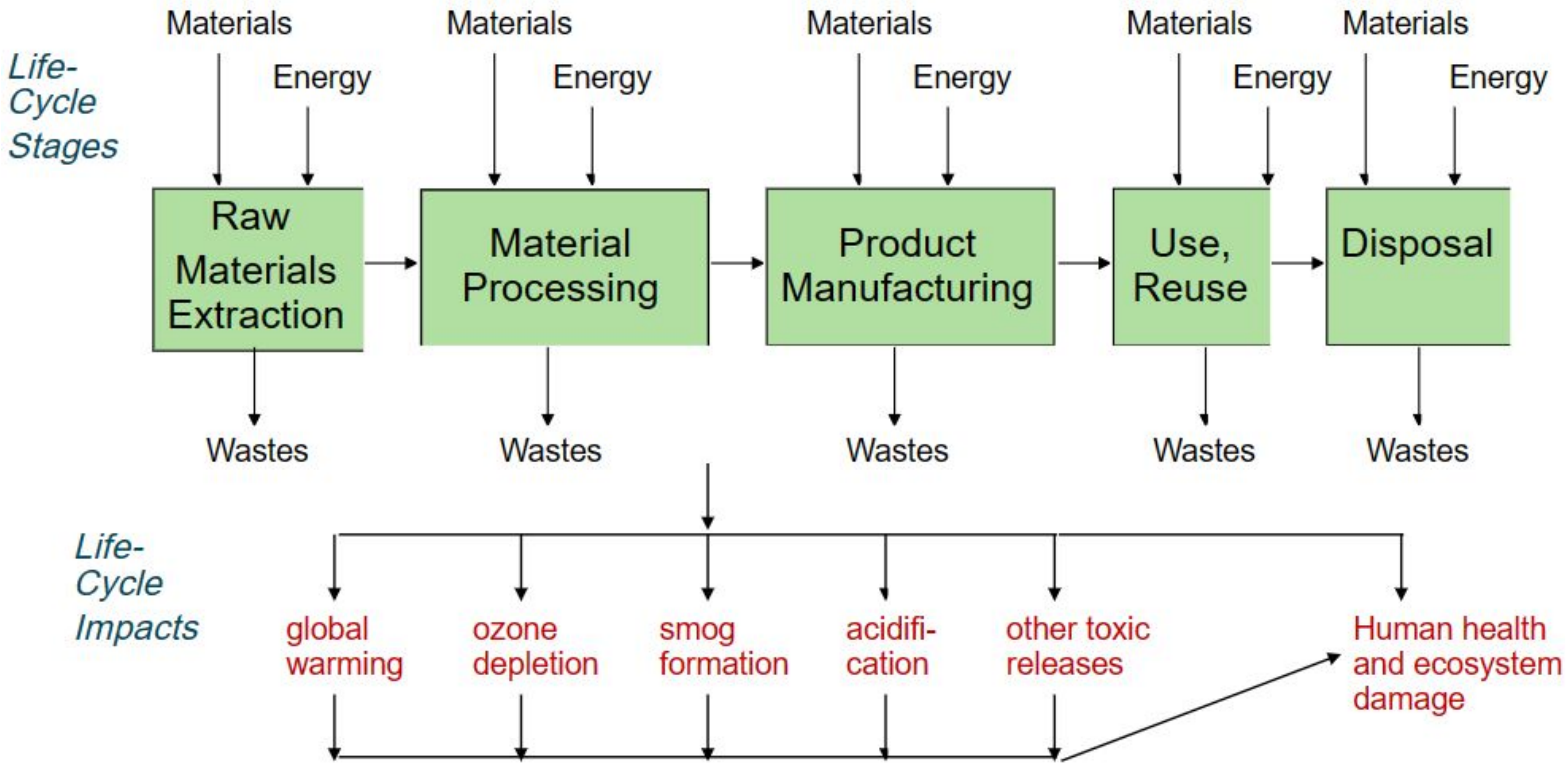


Figure 1.3 Stages of a product life cycle. Environmental impacts occur at all stages. These impacts can be reduced by engineering designs that change the type and/or amount of materials used in a product; by creating more efficient extraction and manufacturing processes; and by improving the recovery and reuse of materials and energy at the end of the product life. (*Source:* Based on OTA, 1992)

LCA has three steps

- **Inventory analysis-** lists all inputs (raw materials and energy) and outputs (products,wastes, and energy), as well as any intermediate outputs.
- **Impact analysis-** lists all of the effects on the environment of each item identified in the inventory analysis, and quantifying or qualitatively describing the consequences(e.g., adverse health effects, impacts on ecosystems, or resource depletion).
- **Improvement analysis-** lists, measures, and evaluates the needs and opportunities to address adverse effects found in the first two steps.

Life Cycle Impacts



-Robert Hesketh

Design for Life Cycle Guidelines

Raw materials - Design for resource conservation - Design for low impact materials	**Manufacturing** - Design for cleaner production
Use - Design for energy efficiency - Design for water conservation - Design for minimal consumption - Design for low-impact use - Design for service and repair - Design for durability	**End of life** - Design for re-use - Design for re-manufacture - Design for disassembly - Design for recycling - Design for safe disposal
Distribution - Design for efficient distribution	

ENGINEERING ECONOMICS IN DESIGN

- COST ESTIMATION: HOW MUCH DOES THIS PARTICULAR DESIGN COST?
- In practice, cost estimation is a complex business that requires skill and experience.
- However, there are several ways that we can break out the cost structure of a device that we are designing.
- The simplest, conceptually, is to estimate labor, materials, and overhead costs.

LABOR, MATERIALS, AND OVERHEAD COSTS

- **Labor costs** include payments to the employees who build the designed device, as well as to support personnel who perform necessary but often invisible tasks such as taking and filling orders, packaging, and shipping the device.
- Labor costs also include a variety of indirect costs that are less evident because they are generally not paid directly to employees.
- These indirect costs are sometimes called fringe benefits and include health and life insurance, retirement benefits, employers' contributions to Social Security, and other mandated payroll taxes.
- A simple starting point for estimating costs is to keep good records or the activities needed to build our design's prototype.

LABOR, MATERIALS, AND OVERHEAD COSTS

- Materials include those items and inputs directly used in building the device, along with intermediate materials and inventories that are consumed in the manufacturing process.
- A key tool for estimating the materials cost of an artifact is the bill of materials (BOM), the list of all of the parts in our design, including the quantities of each part required for complete assembly
- The BOM is particularly useful since it is usually developed directly from the assembly drawings, and so it reflects our final design intentions.
- Materials costs can often be reduced significantly by using commercial off-the-shelf materials rather than making our own.
- This is because outside vendors have the machinery and expertise to make very large numbers of parts for a lot of customers.

LABOR, MATERIALS, AND OVERHEAD COSTS

- The costs incurred by a manufacturer that cannot be directly assigned to a single product are termed overhead.
- Estimating the costs of producing a design requires careful consultation with clients or their suppliers.
- In practice, each engineering discipline has its own approaches to cost estimating that are captured by general guidelines

Economies of Scale: Do We Make It or Buy It?

- The idea that we can reduce the unit production cost of a design by making a lot of copies, rather than just making a few “originals.”
- High volume production allows companies to distribute the costs of specialized and innovative technologies over a lot of units, thus lowering the cost per unit produced.
- This can have a profound effect on our designs.

The Cost of Design and the Cost of the Designed Device

- There is an important distinction between the cost of designing, prototyping, and testing a product and the cost of the product after manufacturing and distribution.
- While costing is an important element in the **profitability** of a design, it is generally not a key factor in the pricing of the artifact.
- Costs are an important element in the profit equation.
- Revenues, on the other hand, are determined by the price charged for an item multiplied by the number of items sold.
- For most profit maximizing firms, prices are not set on the basis of costs, but rather in terms of what the market is willing to pay.
- The responsibilities of marketing professionals on a design team usually include identifying design attributes that make consumers willing to pay a high price for a new product design.

- The (formal) field of engineering economics is concerned with understanding the economic or financial implications of engineering decisions, including choosing among alternatives (e.g., cost–benefit analysis), deciding if or when to replace machines or other systems (replacement analysis), and predicting the full costs of devices over the period of time that they will be owned and used (life cycle analysis).

DESIGN RIGHTS

- What is a design right?
  - If you have created a new design, it's worthwhile considering registering it to effectively prevent others from copying or exploiting your design.
  - A registered design is an excellent and cost-effective tool to protect your rights against copying and counterfeiting.
- A design registration means you can register the look of your product. It gives you an exclusive right to your design for a limited time
- Designs can be registered to protect the look of your whole product, a part of your product, or even just a small detail.
- Your product might be something functional, like a mobile phone, a drill, or a toothbrush, or something more decorative like a vase or a piece of jewelry.

DESIGN RIGHTS

- You can also protect graphical symbols, logos, computer icons, user interface Graphics, with a registered design.
- The design must be new and have individual character over prior design Registrations in order to be registered

ETHICS IN DESIGN

- To design means to accept responsibility for creating designs.
- Designers are influenced by the society in which they work, and designed products influence society.
- That is why we must consider ethics and ethical behavior in our examination of how engineers design things.
- Words like ethics, morals, obligations, and duty are used in a variety of ways in everyday life, including seemingly contradictory or unclear ones

ETHICS: UNDERSTANDING OBLIGATIONS

Ethics

- The discipline dealing with what is good and bad and with moral duty and obligation
- A set of moral principles or values
- A theory or system of moral values
- The principles of conduct governing an individual or group

Moral

- Relating to principles of right or wrong in behavior
- Expressing or teaching a conception of right behavior

- These definitions define ethics as a set of guiding principles or a system that people can use to help them behave well.

Codes of Ethics: What are Our Professional Obligations?

- The professional societies also undertook other kinds of activities, including promulgating design standards, and providing forums for reporting research and innovations in practice.
- The professional engineering societies continue to play a leading role in setting ethical standards for designers and engineers.
- These ethical standards clearly speak to the various and often conflicting obligations that an engineer must meet.
- The societies also provide mechanisms for helping engineers resolve conflicting obligations, and, when asked, they provide the means for investigating and evaluating ethical behavior.
- Most professional engineering societies have published codes of ethics.

Codes of Ethics: What are Our Professional Obligations?

- There are some points to make regarding the professional societies and their codes.
- The differences in the codes reflect different styles of engineering practice in the various disciplines much more than differences in their views of the importance of ethics.
- The professional societies, not withstanding their promulgation of codes of ethics, have not always been seen as active and visible protectors of whistle blowers and other professionals who raise concerns about specific engineering or design instances.
- The codes of ethics we have described are not necessarily the same as those in all parts of the world.

ETHICS: ALWAYS A PART OF ENGINEERING PRACTICE

- Ultimately, ethics is intensely personal
- There is no way to predict when a serious conflict of obligations and loyalties will arise in our individual lives.
- Nor can we know the specific personal and professional circumstances within which such conflicts will be embedded.
- Nor, unfortunately, is there a single answer to many of the questions posed.
- If faced with a daunting conflict, we can only hope that we are prepared by our upbringing, our maturity, and our ability to think and reflect about the issues that we have briefly raised.