Build4 Scale

U.S. Department of Energy

Detailed Design Package

Module 2A Bill of Materials and Bill of Process

Motivation

Why is this module important?

- Even the simplest products are typically complex in structure
- If bill of materials (BOM), bill of process (BOP), and engineering drawings are not crystal clear to the innovator and the manufacturer, it can result wasted money and/or products that are improperly constructed
- It's crucial to know the answers to:
  - —What and how many components form the product?
  - —What are the steps/sequence for fabricating the product?
  - —How can the product continue to be produced effectively as its complexity increases?

Module Outline

- Learning objectives
- Product hierarchy, bill of materials (BOM)
- Process planning, routing sheet, bill of process (BOP)
- Engineering drawing:
  —Component level
  —Assembly level
  —Interpreting engineering drawings
- Case studies

Learning Objectives

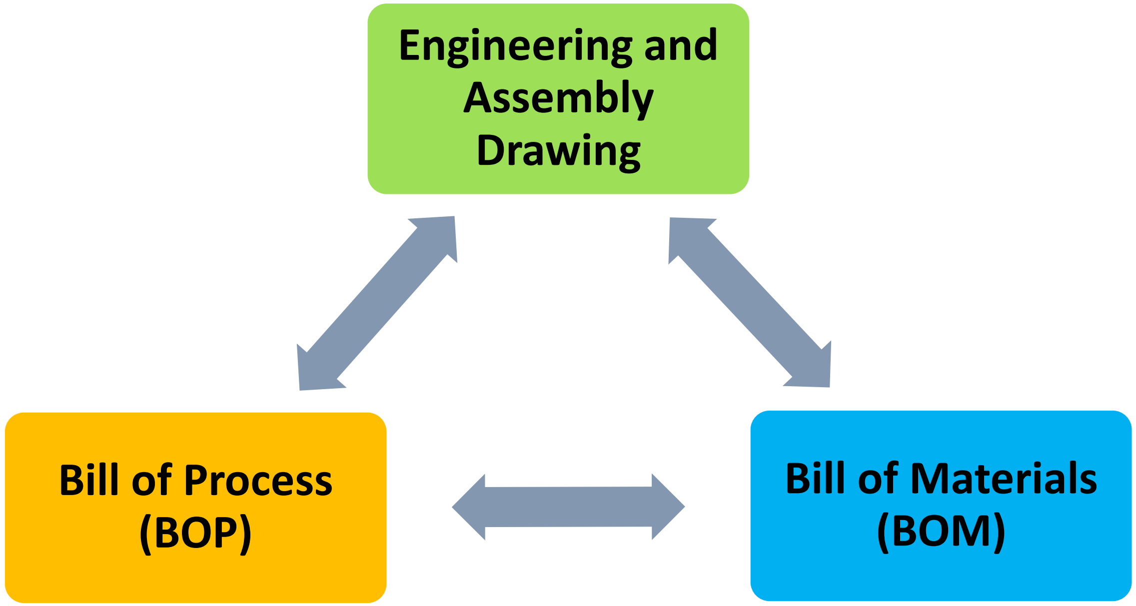
- LO1: Identify product hierarchy and assembly plan
- LO2: Develop appropriate process plan for components
- LO3: Assess engineering drawings for components

What This Module Addresses

- The relationship between BOM, BOP, and engineering drawings
- Basic terminology of BOM, BOP, and engineering drawings
- Some existing online tools to assist in creating a BOM and a BOP
- How to manage BOM generation for complex products

BOP, BOM, And Drawings

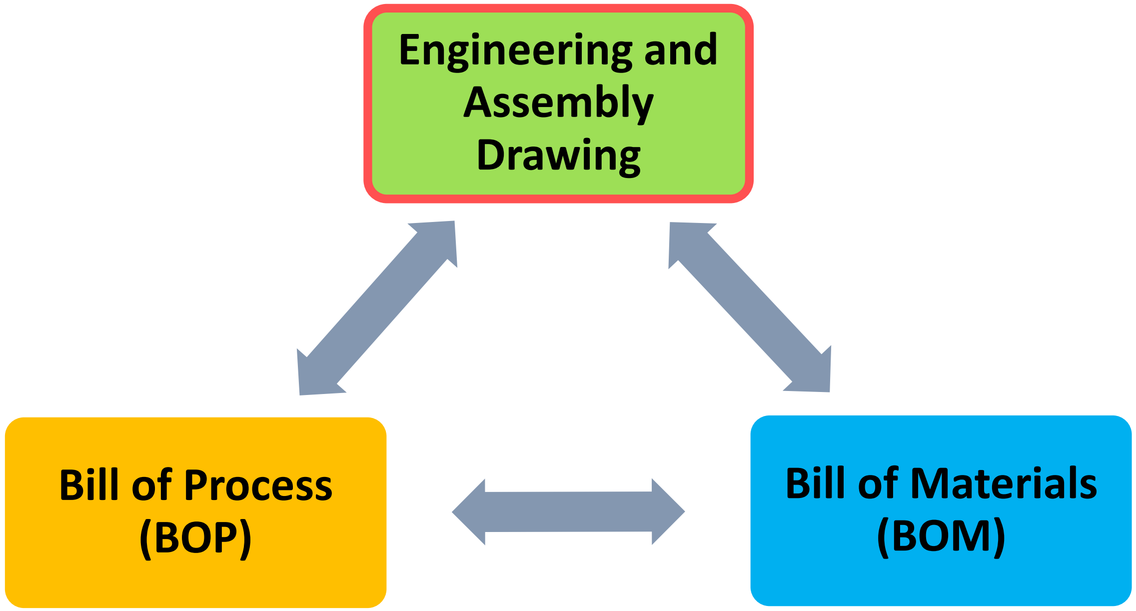
How they all relate



These 3 blocks must be considered simultaneously!

BOP, BOM, And Drawings

How they all relate

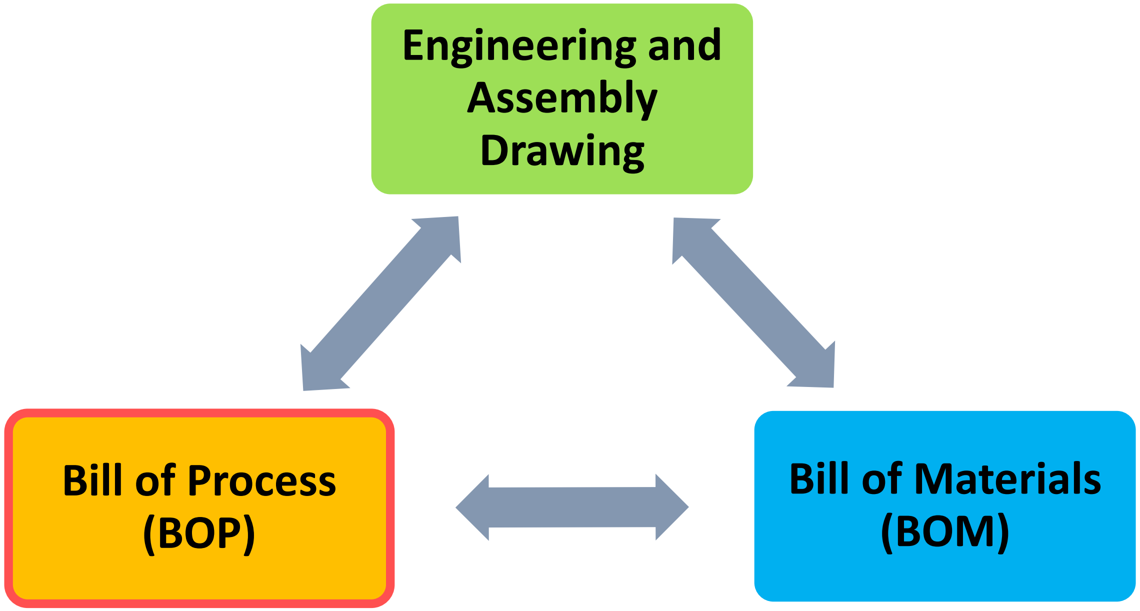


Engineering and assembly drawing provides:

- Visual representation of product and components
- Fit, tolerances, and assembly specifications

BOP, BOM, And Drawings

How they all relate

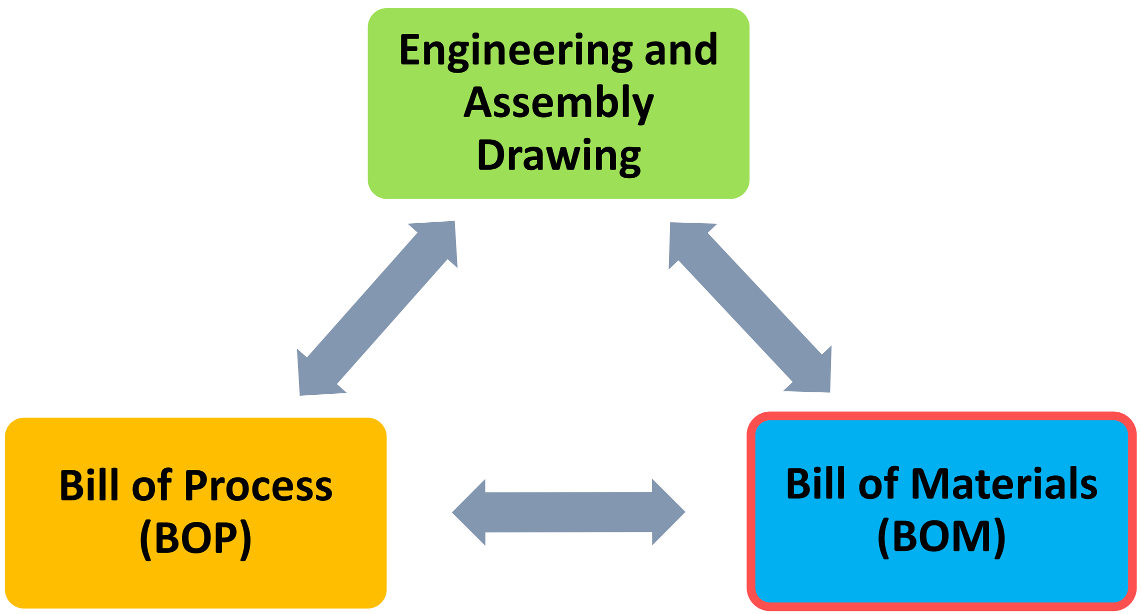


Bill of process (BOP) addresses:

- Processes that produce the product and their sequence
- Specifications and parameters of each process step

BOP, BOM, And Drawings

How they all relate



Bill of materials (BOM) addresses:

- Components forming the product
- Production time per component

Bill Of Materials

Basics

- **Bill of materials (BOM)**: Lists quantities of components, ingredients, and materials required to make a product
- Integrates product hierarchy through parent/child delineation

Levels of a product:

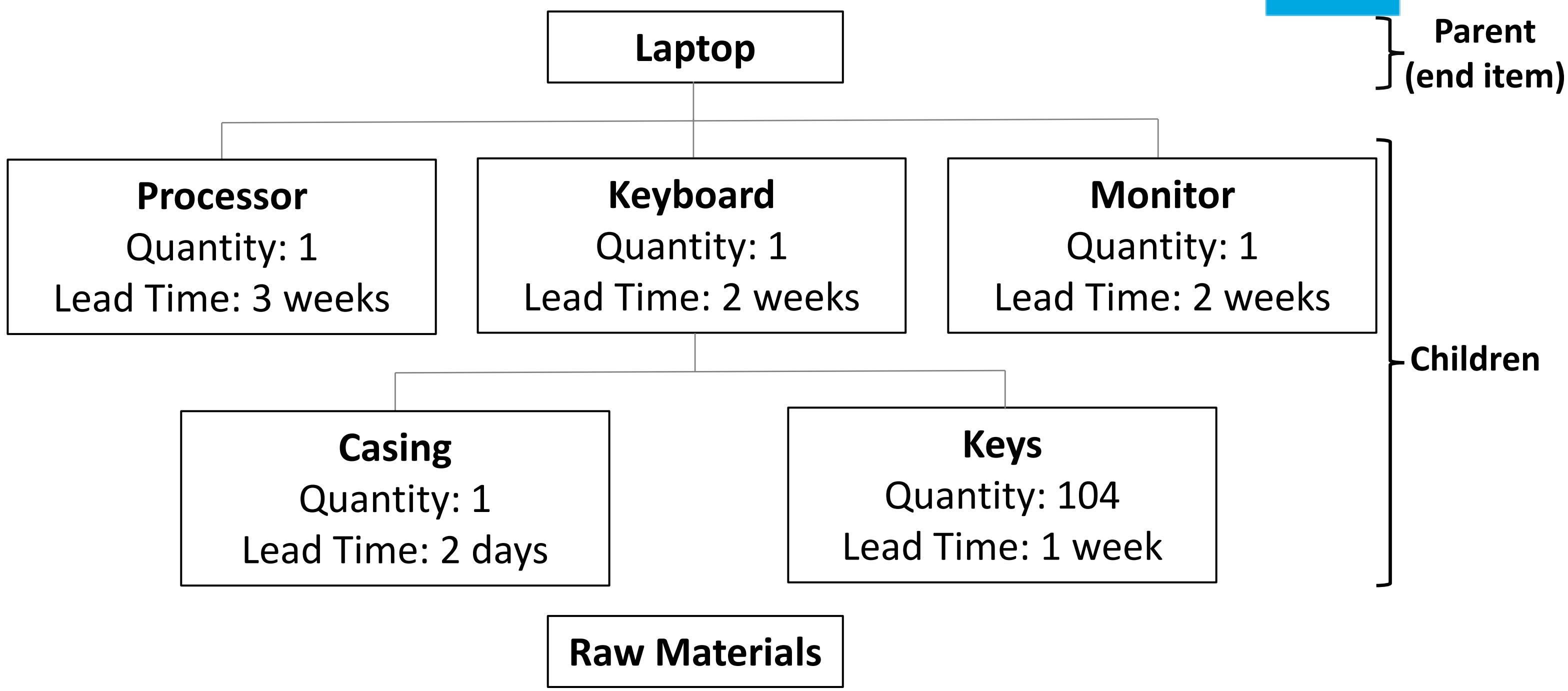
- Parent: End item (or final product)
- Children: Raw materials, components, and sub-assemblies

Demand may depend on product levels:

- Parent: Independent demand (external to the system)
- Children: Dependent demand (internal to the system)—Demand for an item depends on the demand for items ”higher up” on the the BOM

Bill Of Materials

Example - Product hierarchy



The BOM provides information about:

- Relationship between items at different levels
- Quantity of each item
- Lead Time of each item

Bill Of Materials

BOM generation components

Low-level coding (LLC):

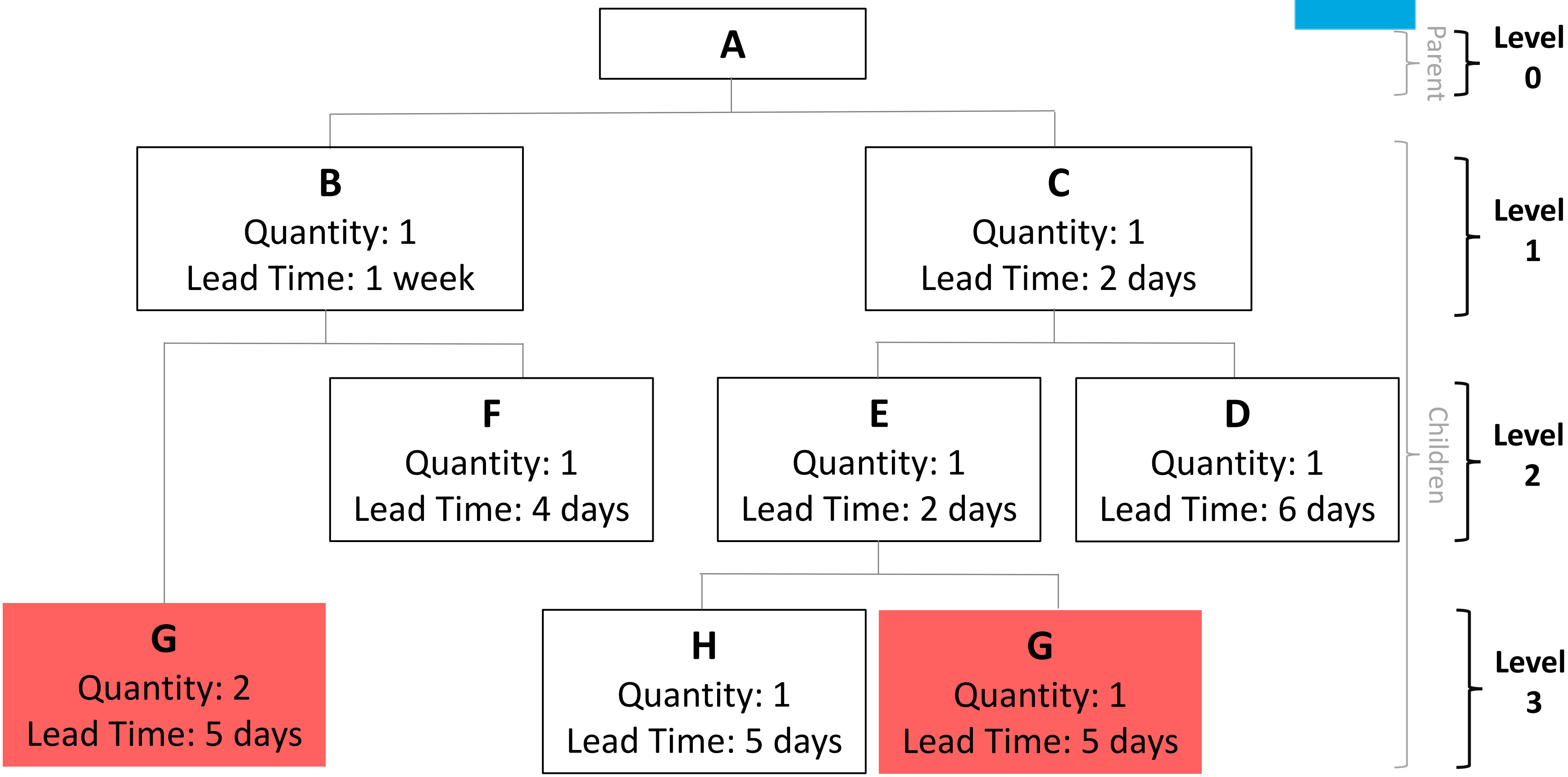
- A number that identifies the lowest level at which a specific item exists in the BOM
- Allows for easily computing the requirements of an item existing at different levels of the BOM

BOM processor:

- Essential component in most commercial packages; maintains the BOM and automatically assigns LLCs
- Is essential for products with large BOMs (e.g., automobiles with approximately 30,000 components)

Bill Of Materials

Example – Lower level coding



- Item G can be coded as Level 2 (under B) or Level 3 (under E)
- LLC convention has it coded as Level 3

Bill Of Materials Tools

Online BOM tools:

- Build and generate BOMs in a standard user-friendly environment
- Scan the BOM for duplicates or redundant parts
- Generate BOM graphical representations
- Enable collaboration across an organization

Examples: Dragon Standard BOM is a free chrome extension for creating BOMs. Commercial solutions include Arena Solutions' Product Lifecycle Management (PLM), Mouser Electronics' Forte, and IQMS Enterprise Resource Planning (ERP) software.

Bill Of Materials

Example – *BOM software*

A	B	C	D	E	F	G	H	I	J	K	L	M
SCANNED?	Part Name	# of STLs	Min GAUGE (mm)	Material_ SPEC.	Weight_(kgs) (Each)	Weight_ Check (Vehicle)	Part Type (Purchased, Purchased Modified, or New)	Piece Cost	Material Selection	Tooling Cost	Styling Release Date	Engineering Release Date
	BRAKES					**76.686**						3/15/2017
R	ABS_CONTROL_MODULE	1	SOLID	ALUMINUM/STEEL/PLASTIC	1.845		p					3/15/2017
N/A	ABS_CONTROL_MODULE_HARDWARE	N/A	N/A	STEEL	0.010		p					
N/A	BRAKE_FLUID	N/A	N/A	LIQUID	0.370		p					
N/A	BRAKE_LINES	N/A	N/A	STEEL	2.770		PM					
N/A	BRAKE_LINES_HARDWARE	N/A	N/A	PLASTIC/STEEL	0.085		p					
N/A	ELECTRONIC_BRAKE_BOOSTER_ASSY	N/A	N/A	N/A	5.260	5.245	p					
R	ELECTRONIC_BOOSTER	1	SOLID	ALUMINUM/PLASTIC	0.510		p					
N/A	ELECTRONIC_BRAKE_BOOSTER_HARDWARE	N/A	N/A	RUBBER/STEEL	0.020		p					
R	MASTER_CYLINDER	1	3.00	ALUMINUM/PLASTIC/STEEL	4.450		p					
R	MASTER_CYLINDER_RESERVOIR	1	MULTIPLE	PLASTIC	0.265		p					
	REAR_BRAKES					31.421						
	BRAKE_CALIPER_LH		SOLID	ALUMINUM	3.255		p					
	BRAKE_CALIPER_RH		SOLID	ALUMINUM	3.270		p					
	BRAKE_ROTOR_LH		SOLID	STEEL	9.385		p					
	BRAKE_ROTOR_RH		SOLID	STEEL	9.410		p					
	DUST_COVER_LH		1.48	ALUMINUM	0.360		N					
	DUST_COVER_RH		1.48	ALUMINUM	0.360		N					
	EMERGENCY_BRAKE_LH		SOLID	ALUMINUM/PLASTIC	2.445		p					
	EMERGENCY_BRAKE_RH		SOLID	ALUMINUM/PLASTIC	2.445		p					
	PARKING_BRAKE_CLIPS				0.001		p					
	REAR_BRAKE_HARDWARE				0.490		p					

BIW | **Brakes** | Bumpers | Closures | Cooling | Electrical | Exterior Plastic & Trim | Interior Plastic & Trim | IP | PowerTrain | Seats | Suspension & Chassis

Process Planning

Basics

- Process planning is typically documented on a routing sheet, also known as a **bill of process** (BOP)

Process planning organizes these production-related elements:

- Methods of production
- Tooling
- Fixtures
- Machinery
- Sequence of operations
- Processing time of operations
- Assembly methods

Process Planning

Key considerations

Factors to be considered during process planning:

- Dimensions/size
- Surface finish
- Geometric shape
- Tolerance
- Material being processed
- Product value and urgency
- Manufacturing capabilities and resources available

Process Planning

Example

PROCESS PLAN — ACE Inc.

Part No. S0125-F
Part Name: Housing
Original: S.D. Smart Date: 1/1/2017
Checked: C.S. Good Date: 2/1/2017

Material: steel 4340Si
Changes: ________ Date : ________
Approved: T.C. Chang Date : 2/14/2017

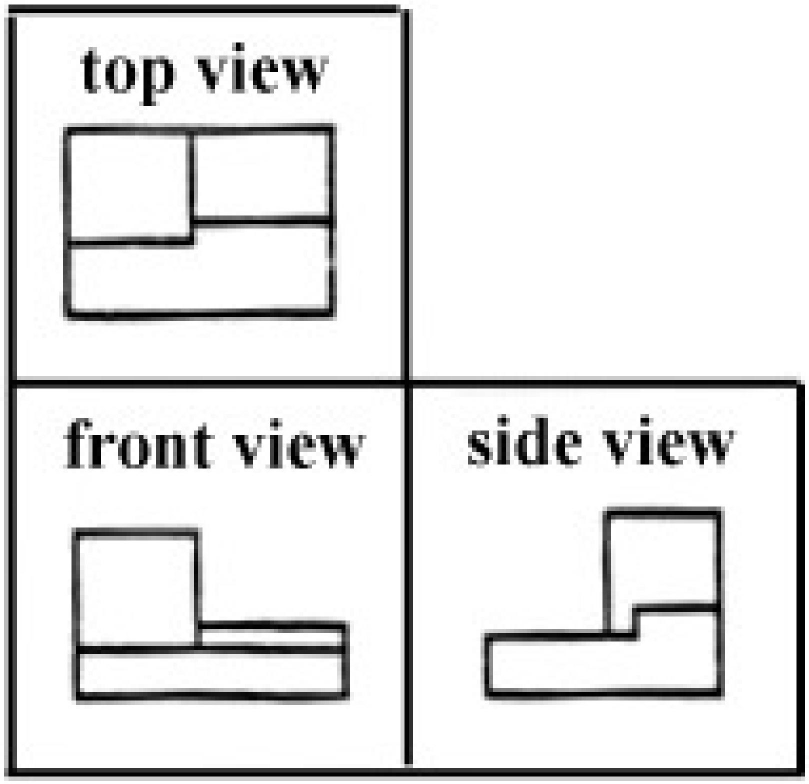
No.	Operation Description	Workstation	Setup	Tool	Time (Min)
10	Mill bottom surface1	MILL01	see attach#1 for illustration	Face mill 6 teeth/4" dia	3 setup 5 machining
20	Mill top surface	MILL01	see attach#1	Face mill 6 teeth/4" dia	2 setup 6 machining
30	Drill 4 holes	DRL02	set on surface1	twist drill 1/2" dia 2" long	2 setup 3 machining

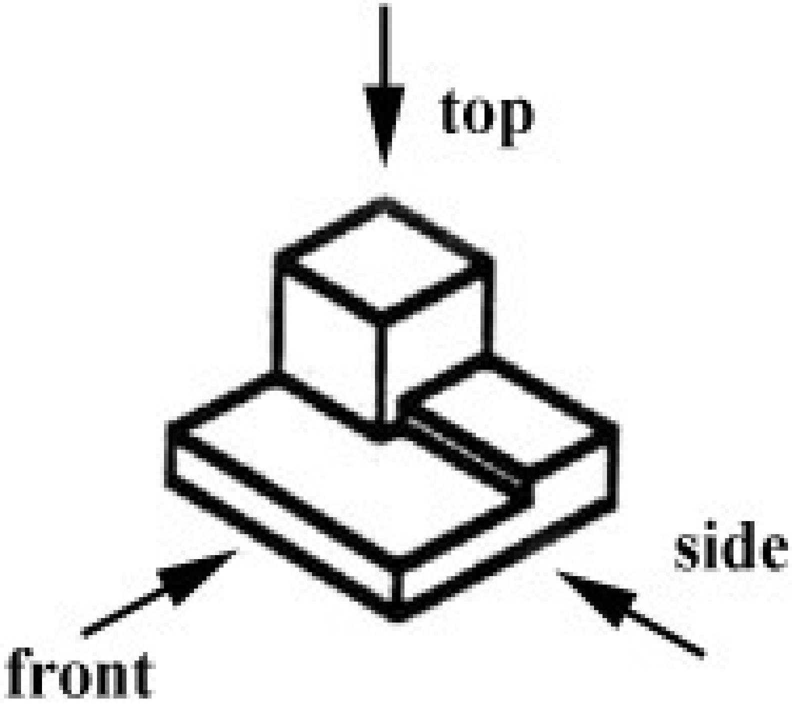
Source: https://www.slideshare.net/GuhanM/process-planning-34794073

Engineering Drawings

Example - Component level

- Represent 3D objects in 2D by projecting the object's shape onto a plane

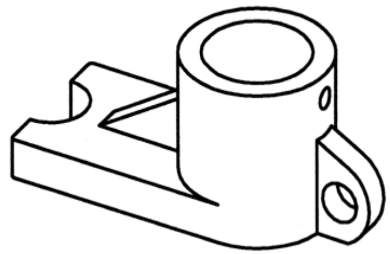




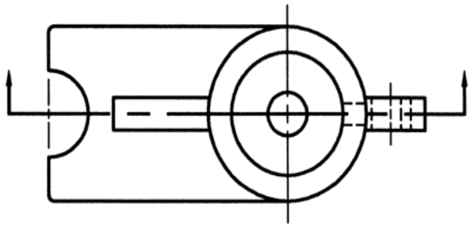
Engineering Drawings

Example – Internal features

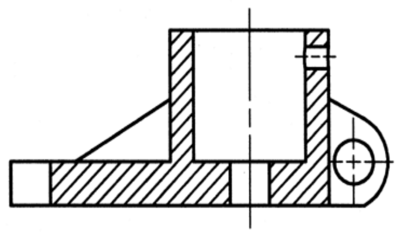
- Represent internal features of components using sectional views
- This is important to distinguish between hollow components and solid components



3D view of a component



Indicates where the section was taken



Corresponding sectional view (demonstrating internal features)

Engineering Drawings

Dimensional tolerances

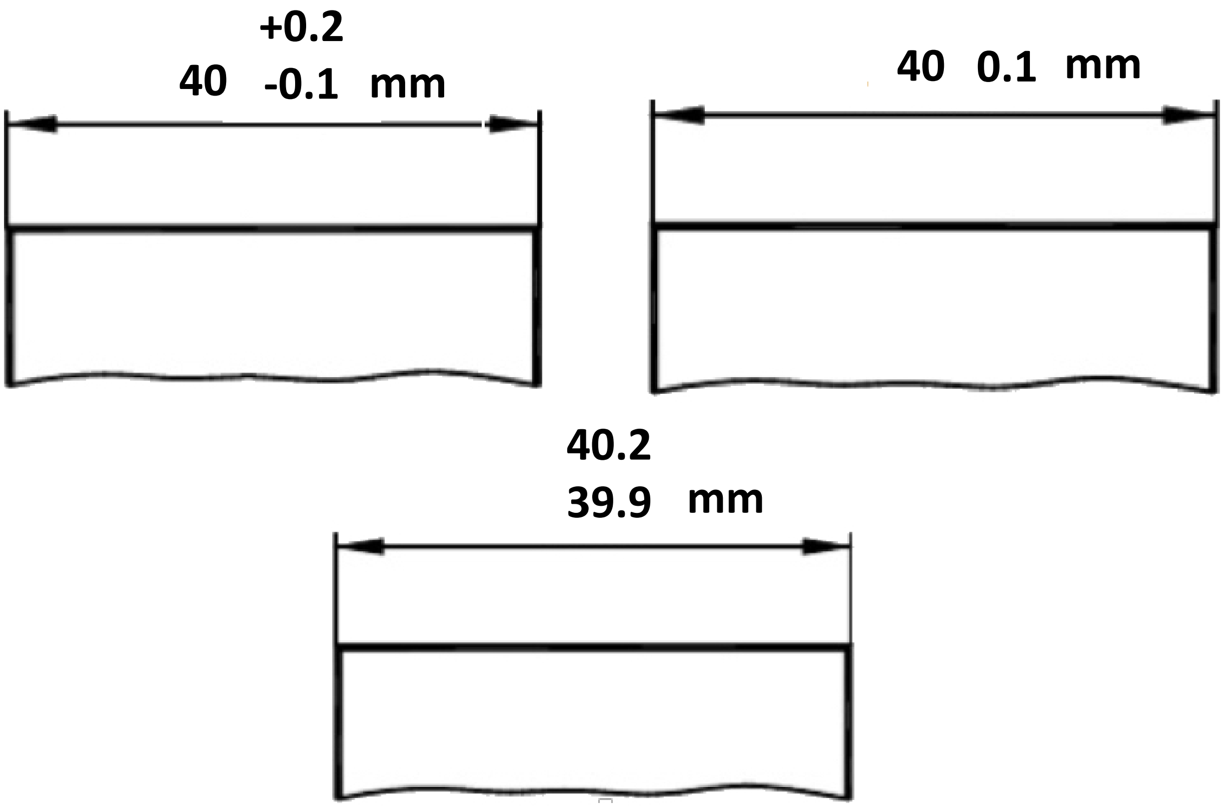
Dimensional tolerances:

- Defined as the allowable errors on a specific dimension
- Typically expressed as a range of values (i.e., the diameter of a hole is expressed as “3.5 inches ± 0.02,” which means that the hole is acceptable as long as its actual manufactured diameter is between 3.48 and 3.52 inches in diameter)

Engineering Drawings

Introduction to dimensional tolerances

- Representing dimensional tolerances on a component's drawing



More detailed examples here -
https://www.nmri.go.jp/eng/khirata/metalwork/basic/accuracy/index_e.html

Engineering Drawings

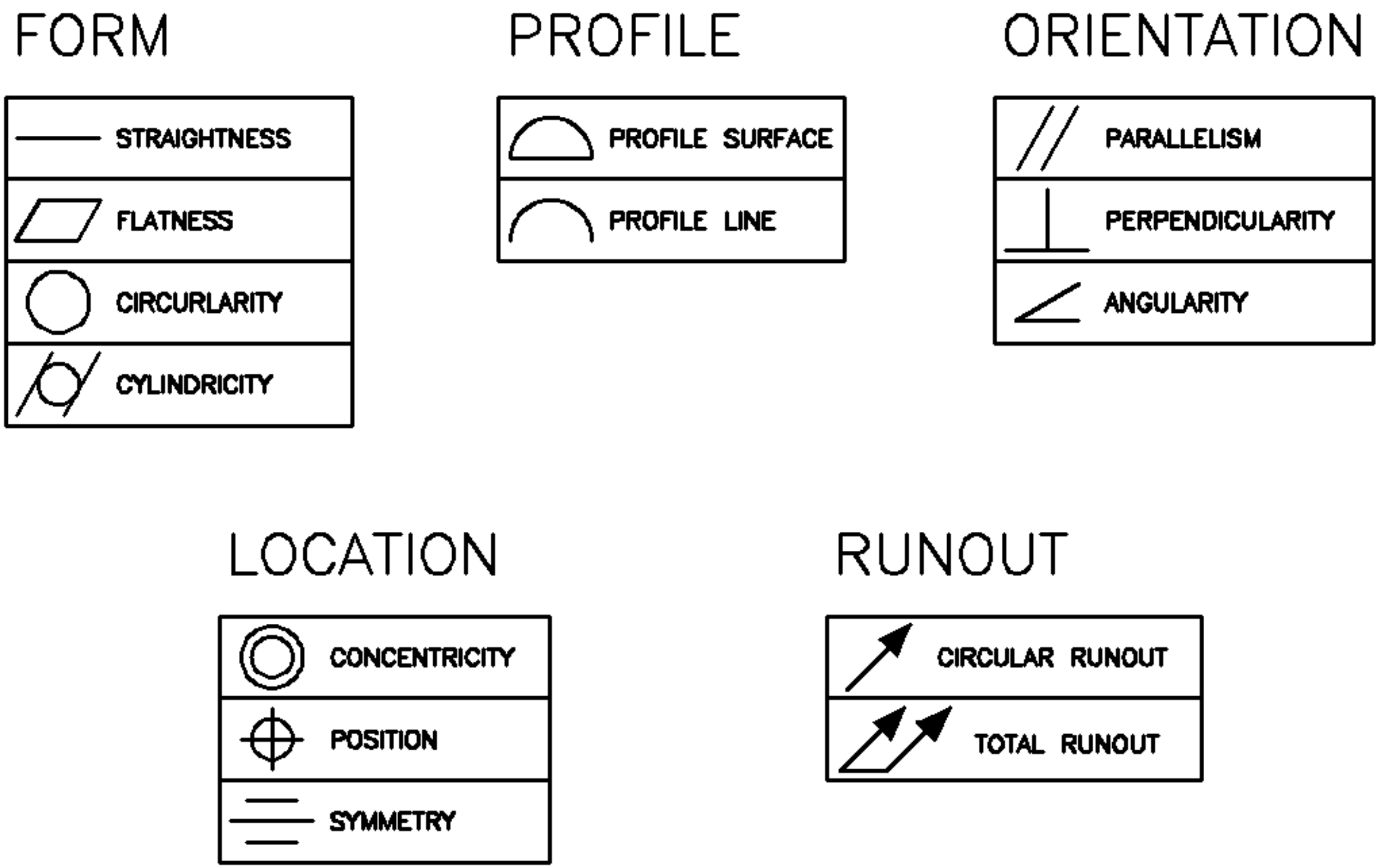
Geometric tolerances

Geometric tolerances:

- Defined as the allowable errors on shapes, locations, and profiles (as opposed to size or dimensional tolerances)
- Specified on engineering drawings as a box with a leader connected to the feature of interest

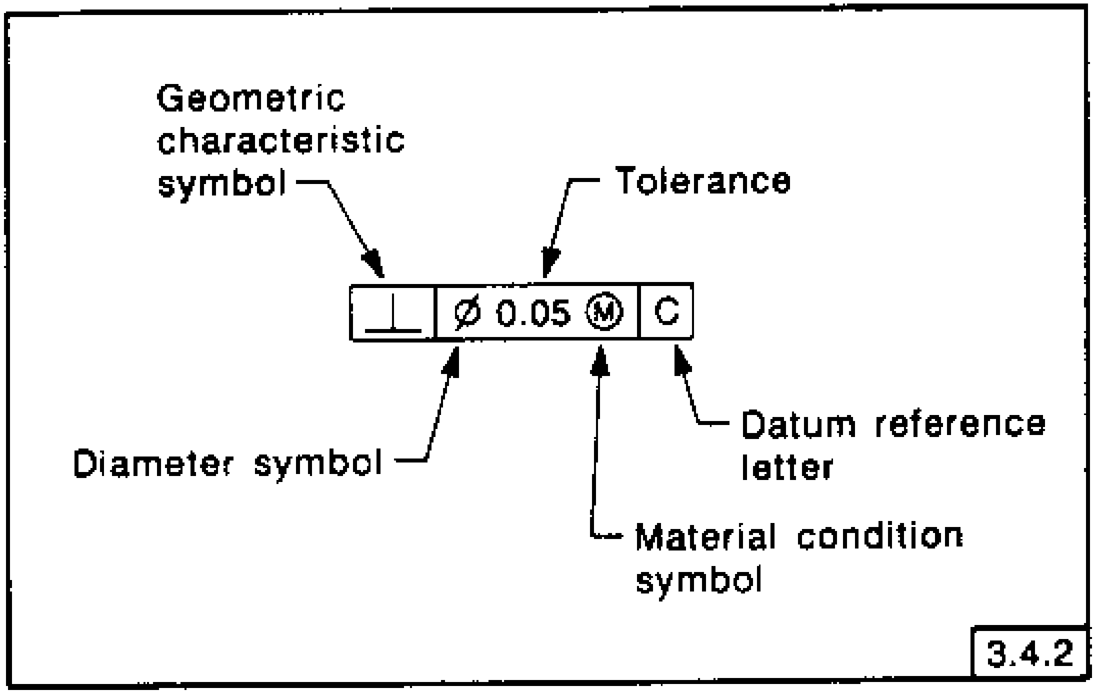
Engineering Drawings

Main types of geometric tolerances



Engineering Drawings

Example - Geometric tolerances



- This feature control frame is read as: "The specified feature must lie **perpendicular** within a **tolerance zone of 0.05 diameter** at the **maximum material condition**, with respect to **datum axis C**

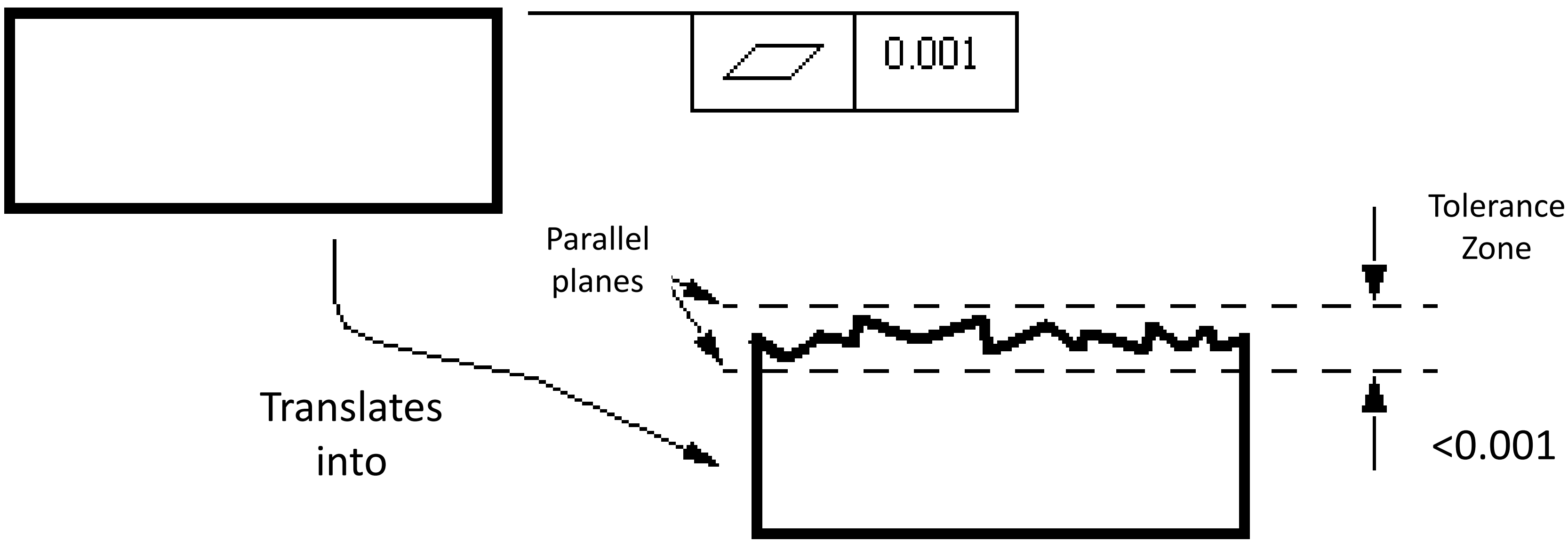
- In other words, this places a limit on the amount of variation in perpendicularity between the feature axis and the datum axis. In a drawing, this feature control frame would accompany dimensional tolerances that control the feature size and position

Source: https://www.joshuanava.biz/engineering-4/geometric-tolerancing.html

Engineering Drawings

Example – Flatness geometric tolerance

Engineering drawing indicating desired flatness outcome



Manufactured product within specifications of the engineering drawing

Engineering Drawings

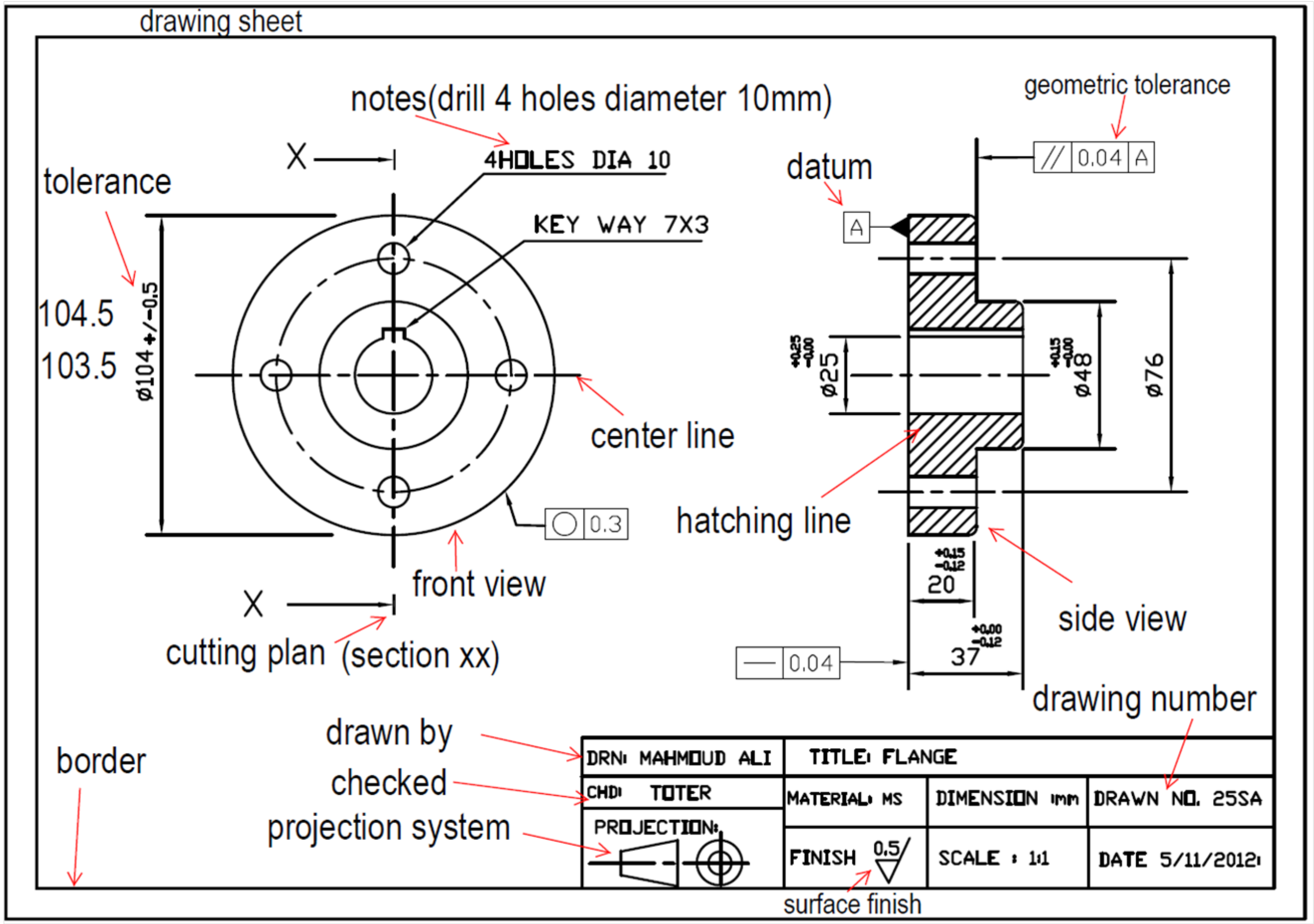
How to interpret them

Information on an engineering drawing or "blueprint":

- Title
- Version
- Material
- Projection type
- Units
- Scale
- Other (i.e., assembly instructions, intellectual property, tolerances)

Engineering Drawings

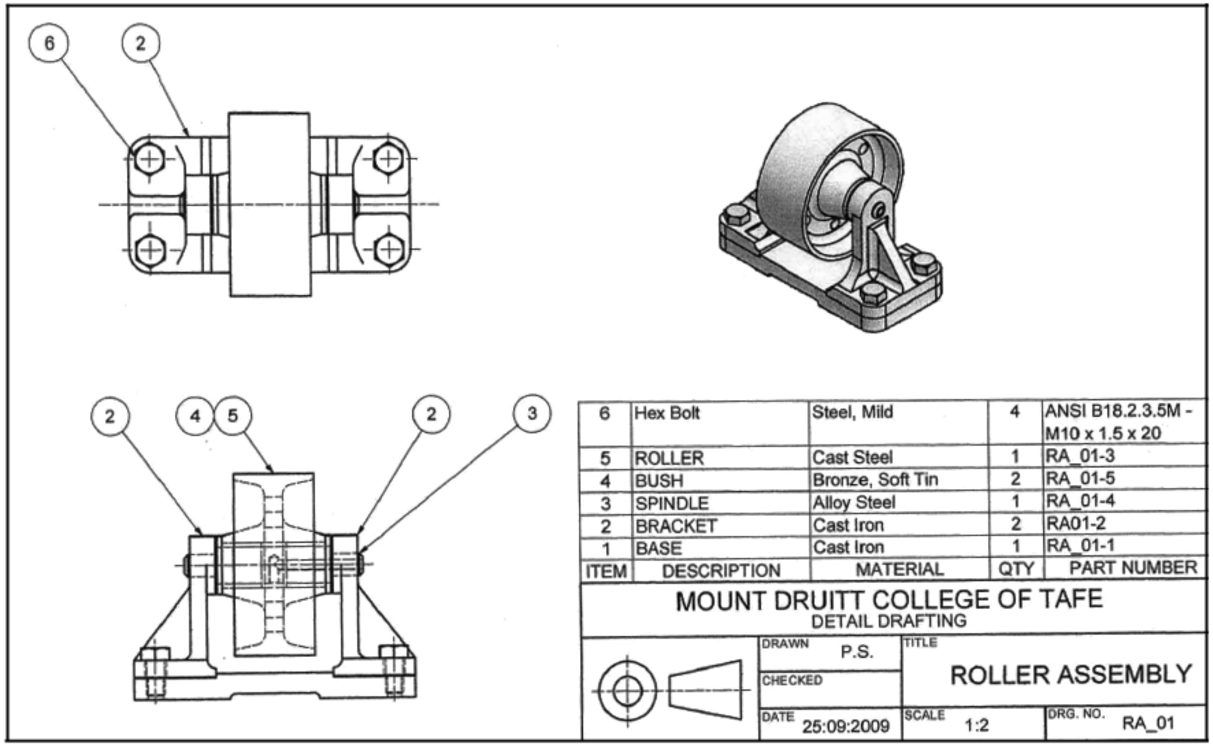
Example - Interpreting the blueprint



Engineering Drawings

Example – Assemblies

- Assembly drawings are engineering drawing representations of the BOM

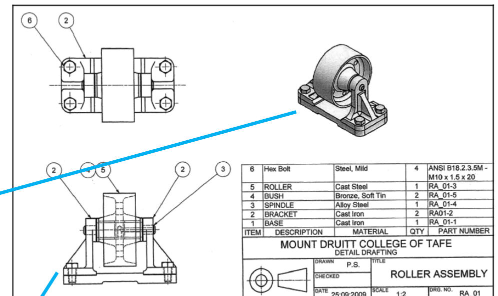


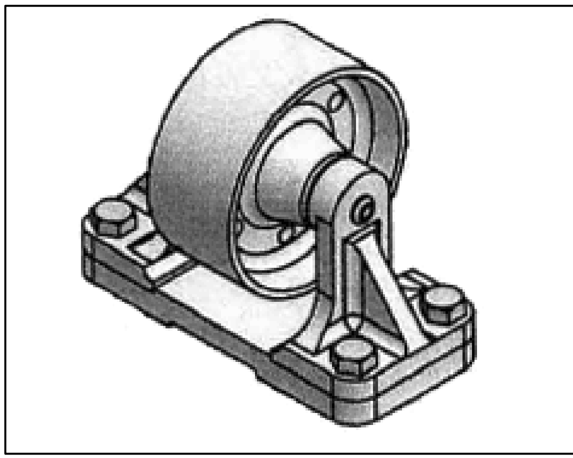
6	Hex Bolt	Steel, Mild	4	ANSI B18.2.3.5M - M10 x 1.5 x 20
5	ROLLER	Cast Steel	1	RA_01-3
4	BUSH	Bronze, Soft Tin	2	RA_01-5
3	SPINDLE	Alloy Steel	1	RA_01-4
2	BRACKET	Cast Iron	2	RA01-2
1	BASE	Cast Iron	1	RA_01-1
ITEM	DESCRIPTION	MATERIAL	QTY	PART NUMBER

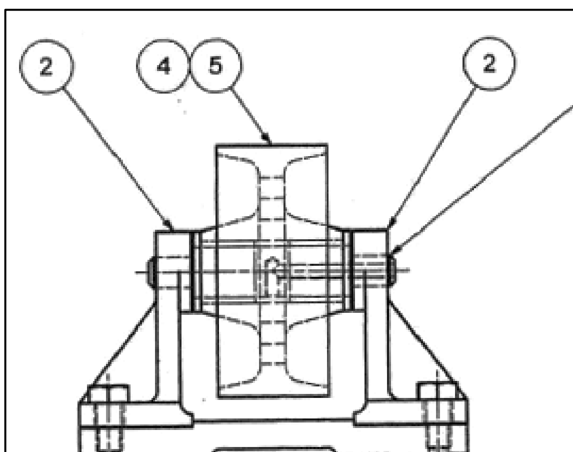
Enlarged on next slide

Engineering Drawings

Example – Assemblies (cont.)







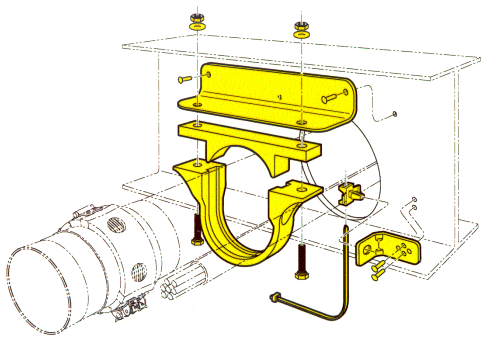
6	Hex Bolt	Steel, Mild	4	ANSI B18.2.3.5M - M10 x 1.5 x 20
5	ROLLER	Cast Steel	1	RA_01-3
4	BUSH	Bronze, Soft Tin	2	RA_01-5
3	SPINDLE	Alloy Steel	1	RA_01-4
2	BRACKET	Cast Iron	2	RA01-2
1	BASE	Cast Iron	1	RA_01-1
ITEM	DESCRIPTION	MATERIAL	QTY	PART NUMBER

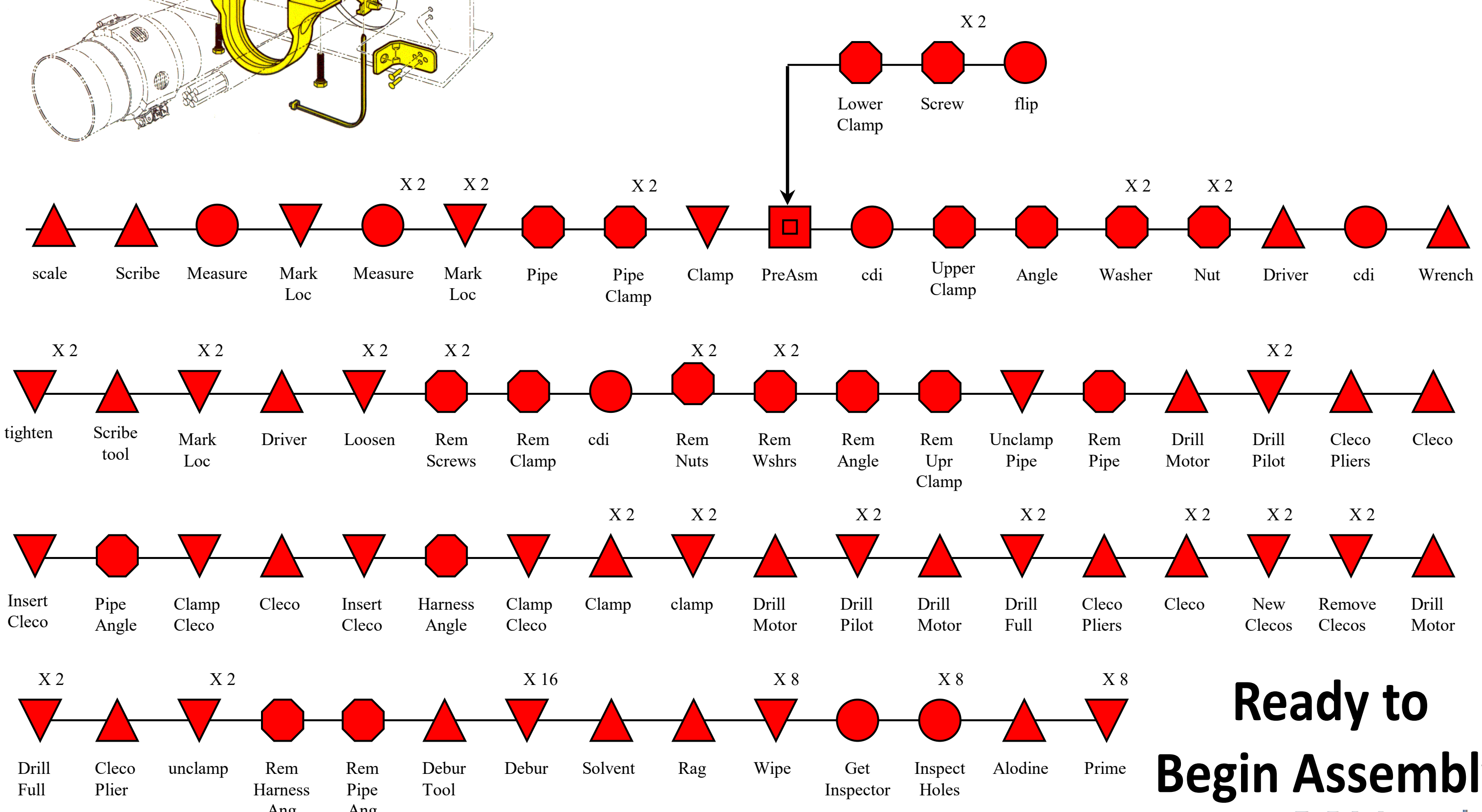
MOUNT DRUITT COLLEGE OF TAFE
DETAIL DRAFTING

DRAWN P.S.
CHECKED
DATE 25:09:2009
TITLE ROLLER ASSEMBLY
SCALE 1:2
DRG. NO. RA_01

BOP Assembly Map

Example 1 - Initial waste pipe bracket

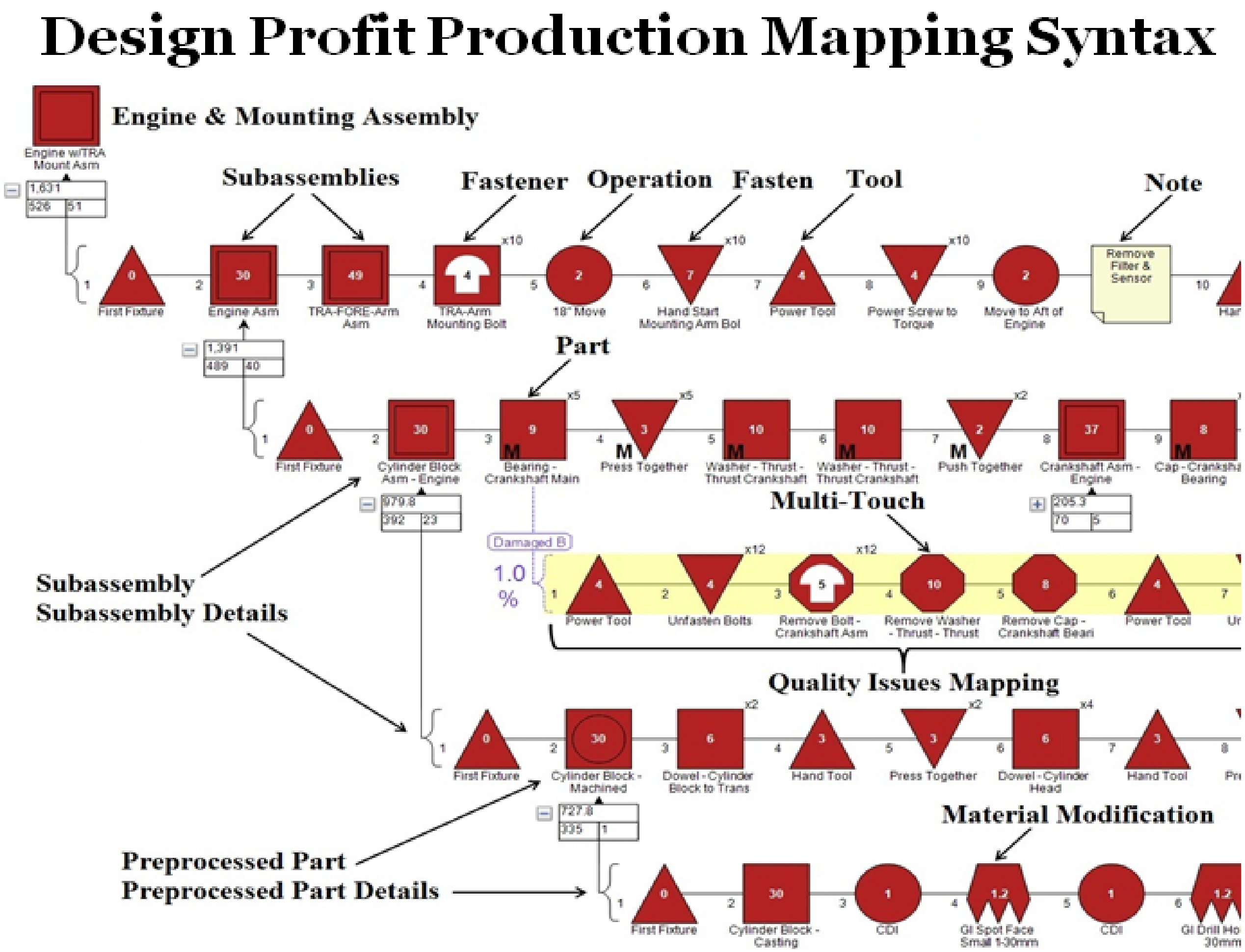




Ready to Begin Assembly

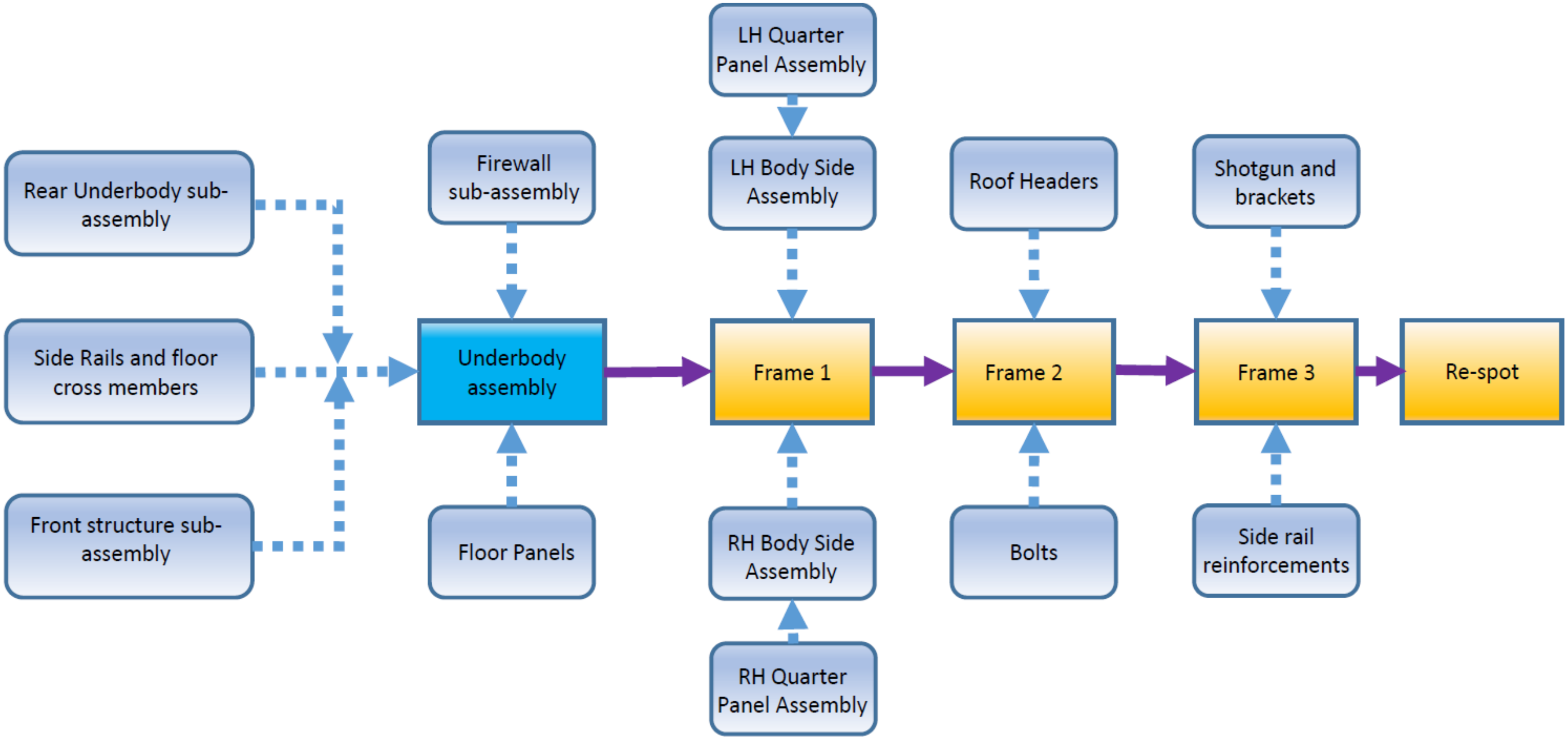
BOP Assembly Map

Example 2



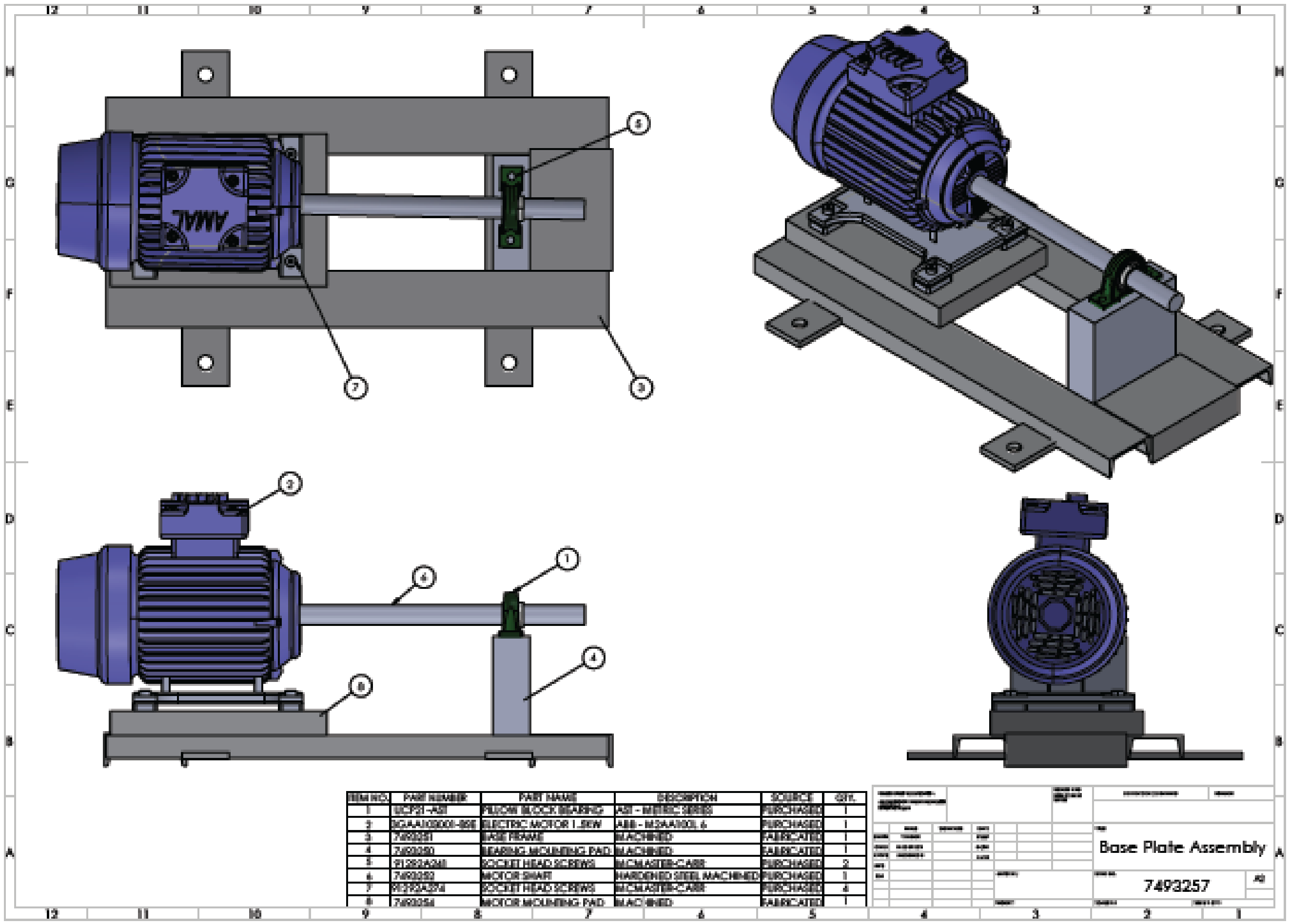
BOP Assembly Map

Example 3 – Car Assembly Line



Engineering Drawing

Example

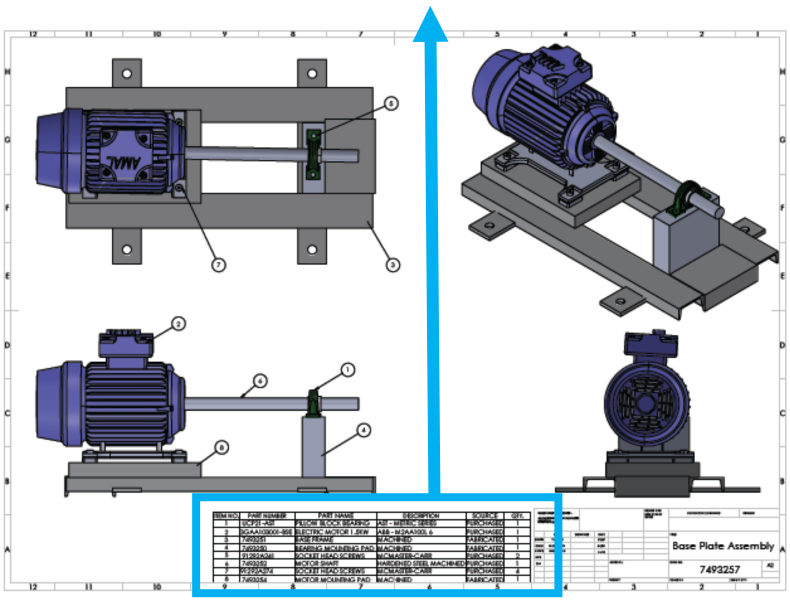


ITEM NO.	PART NUMBER	PART NAME	DESCRIPTION	SOURCE	QTY.
1	UCP21-ASI	PILLOW BLOCK BEARING	ASI - METRIC SERIES	PURCHASED	1
2	3GAA1X3001-8SE	ELECTRIC MOTOR 1.5KW	ABB - M2AA100L 6	PURCHASED	1
3	7493251	BASE FRAME	MACHINED	FABRICATED	1
4	7493250	BEARING MOUNTING PAD	MACHINED	FABRICATED	1
5	91292A268	SOCKET HEAD SCREWS	MCMASTER-CARR	PURCHASED	2
6	7493252	MOTOR SHAFT	HARDENED STEEL MACHINED	PURCHASED	1
7	91292A274	SOCKET HEAD SCREWS	MCMASTER-CARR	PURCHASED	4
8	7493254	MOTOR MOUNTING PAD	MACHINED	FABRICATED	1

Bill Of Materials

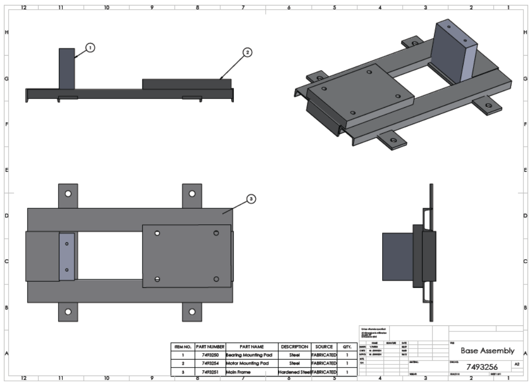
Example – BOM on an engineering drawing

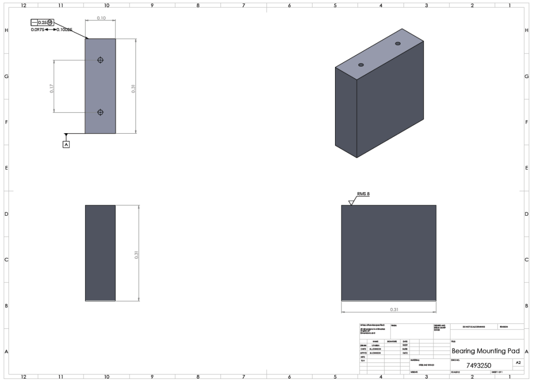
ITEM NO.	PART NUMBER	PART NAME	DESCRIPTION	SOURCE	QTY.
1	UCP21-AST	PILLOW BLOCK BEARING	AST - METRIC SERIES	PURCHASED	1
2	3GAA103001-BSE	ELECTRIC MOTOR 1.5KW	ABB - M2AA100L 6	PURCHASED	1
3	7493251	BASE FRAME	MACHINED	FABRICATED	1
4	7493250	BEARING MOUNTING PAD	MACHINED	FABRICATED	1
5	91292A241	SOCKET HEAD SCREWS	MCMASTER-CARR	PURCHASED	2
6	7493252	MOTOR SHAFT	HARDENED STEEL MACHINED	PURCHASED	1
7	91292A274	SOCKET HEAD SCREWS	MCMASTER-CARR	PURCHASED	4
8	7493254	MOTOR MOUNTING PAD	MACHINED	FABRICATED	1

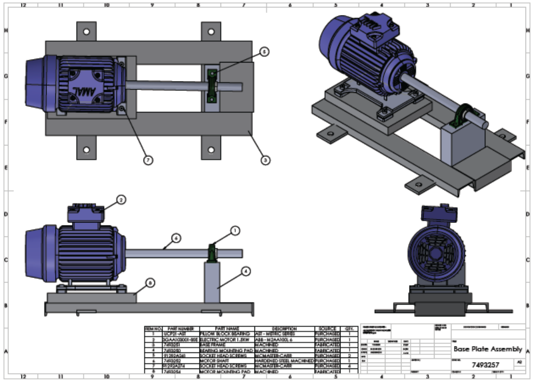


BOP, BOM, And Drawings

Example







Base Plate Assembly

8. Motor Mounting Pad

1. Bearing Mounting Pad

2. Motor Mounting Pad

3. Main Frame

4. Angle Mounting Brackets

5. Cross Supports

These items correspond to the line number in the BOM on previous slide

BOM/BOP

Case study 1 – LED light bulb

Background:

- Hyperion is developing a LED bulb that will replace the conventional high-intensity discharge (HID), metal halide, and high-pressure sodium bulbs used in ornamental sidewalk lamps. The bulb referred to here as the B1 has developed through two major iterations, the B1-a and the B1-b, with numerous development iterations between the versions

Note: Throughout the Build4Scale modules, we'll include product case studies that illustrate what one company experienced as they were developing their products. We have changed the company name and anonymized their product, but we hope that their experience will help you avoid the pitfalls they encountered and shed light on the lessons they learned along the way.

Bill Of Materials

Case study 1 – LED light bulb (cont.)

- Using the BOM, Hyperion was able to identify which components would provide the most overall value for product cost reduction and design optimization.
- Instead of looking at every single component in the BOM, Hyperion was able to focus its attention on a few components that would greatly affect cost and time
- In this case, the BOM was used to identify component hierarchy based on the function, materials, and cost of production
- Hyperion was able to clearly identify the fan assembly as a prime target for cost reduction with a percentage of total cost at scale of 43.2%

Bill Of Materials

Case study 1 – LED light bulb (cont.)

Category	Item	Order QTY	QTY	Unit Cost	Total Cost	Cost@ 1000 QTY	Ratio
Core assembly	Bulb Converter	1	1	$ 2.18	$ 2.18	$ 2,180.00	28.5%
	Fan Assembly	1	1	$ 3.30	$ 3.30	$ 3,300.00	43.2%
	Screw	2	10	$ 0.01	$ 0.03	$ 26.00	0.3%
	Converter Harness	1	1	$ 0.45	$ 0.45	$ 450.00	5.9%
	Module Harness	1	1	$ 0.23	$ 0.23	$ 230.00	3.0%
	O-Ring	1	1	$ 0.26	$ 0.26	$ 260.00	3.4%
	Double Sided Tape	24	1	$ 0.01	$ 0.22	$ 216.00	2.8%
	Copper Tape	2	1	$ 0.49	$ 0.97	$ 974.00	12.8%
	Sub Total	***33***		***$ 6.93***	***$ 7.64***	***$ 7,636.00***	***100.0%***

Bill Of Process

Case study 1 – LED light bulb (cont.)

- By coding their production into a running list of processes (or BOP) and tracking iterations using version control, the company documented changes in their prototype production processes to later be carried into a manufacturing iteration
- The BOP and the BOM are the foundation upon which further product development can be built from prototype to manufacturing. They will be a continuous trunk of information running through all future iterations

Manufacturing Process

Case study 1 – LED light bulb (cont.)

- As the team began production of the lamp end cap, the quantity of production began to dictate the manufacturing process
- The decision came down to the manufacturing process that had the lowest cost
- Initial prototyping was completed at the Los Angeles Advanced Cleantech Incubator (LACI) Prototyping Center to allow for rapid iteration development

Manufacturing Process

Case study 1 – LED light bulb (cont.)

- As the demonstration sites were coming online, Hyperion moved production to a silicon mold cast contractor to handle the increased quantities

Number of Parts Needed	Manufacturing Process	Production Site
1-100	3D Printing	Prototyping Center
50-500	Silicon Mold Casting	Contractor
2,000-10,000	Injection Molding	Contractor

Scale-Up Effects On BOM/BOP

Tradeoffs

So many tradeoffs—how do you evaluate?

Material tradeoffs:

- Different materials require different tools and production processes, each with their own trade-offs
- Reduced cost of materials may mean higher per-piece price with volume if the new material requires a more expensive production process
- More robust materials may require larger investment in tooling and capital equipment
- Lighter weight does not necessarily mean less material

See Module 3B for more details on material selection

Scale-Up Effects On BOM/BOP

Tradeoffs (cont.)

Manufacturing process tradeoffs:

- Lower volumes require different manufacturing process to control tooling and capital equipment investments
- Switch to high volume with less takt time process may require major investment in capital equipment but lower per-piece price over time

See Module 3C for more details on manufacturing processes

Material Selection

Case study 2 - Outdoor LED retrofit bulb

1. Determine the operating environment: Industrial/power plants—the lamp would experience high temperatures and vibration

2. Summarize and prioritize the functional needs based on the operating environment (ideally quantify needs):
   - a. Structurally strong
   - b. Operate at high heat (500 – 700 °C)
   - c. Cost effective

3. Explore your material options based on availability, general cost, weight, manufacturability, etc. Determine options to be:
   - Polycarbonate
   - Stainless Steel

Material Selection

Case study 2 - Outdoor LED retrofit bulb (cont.)

4. With material selection narrowed down evaluate each based on three criteria in step 2

5. Final decision: Because of the unique operating conditions, we preferred **stainless steel**

Key determining factors are circled below:

Material	Operating T (°C)	Strength	Weight	Cost
Polycarbonate	100	Lower	Lighter	Lower
Stainless steel	800	Higher	Heavier	Higher

- Stainless steel - Not as attractive because of higher cost and weight but still preferred due to strength and operation in heat
- Polycarbonate - Attractive because it's lower in weight and cost but these are secondary factors

Scale-Up Effects On BOM/BOP

Material	Low Volume	Medium Volume	High Volume
	Higher per-piece cost, Low-cost tooling	Lower per-piece cost, Higher tooling cost	Lowest per-piece cost, Higher capital equipment, tooling cost
Metal	Machine from Billet, Additive Mfg	Soft Tooling (Casting)	Hard Tooling (Stamping Die, Extrusion)
Plastic	Machine from Billet, Additive Mfg	Rotational Molding, Blow Molding, Thermoforming	Injection Molding, Extrusion, Pultrusion
Composite	Hand Layup, Additive Mfg	RTM, VARTM, Compression Molding	Injection Molding, Pultrusion, Filament Winding

- The use of materials and manufacturing process is not only dictated by volume but also by tolerance requirements and design priorities

Note: Definition of processes found on the next page

See Module 3B and 3C for more details

Scale-Up Effects On BOM/BOP

Description of Molding Methods

- **Resin transfer molding** (**RTM**) is an increasingly common form of **molding**, using liquid composite https://www.azom.com/article.aspx?ArticleID=8620
- **Vacuum Assisted Resin Transfer Molding (VARTM**) or **Vacuum Injected Molding (VIM**) is a closed **mold**, out of autoclave (OOA) composite manufacturing **process** https://en.wikipedia.org/wiki/Vacuum_assisted_resin_transfer_molding
- **Pultrusion** is a continuous process for manufacture of composite materials with constant cross-section https://en.wikipedia.org/wiki/Pultrusion
- **Hand lay-up** is a **molding process** where fiber reinforcements are placed by hand then wet with resin http://www.coremt.com/processes/hand-lay-up/
- **Compression molding** is a forming process in which a plastic material is placed directly into a heated metal mold, then is softened by the heat, and forced to conform to the shape of the mold as the mold closes once molding is completed excess flash are removed, in-order to get best finish https://en.wikipedia.org/wiki/Compression_molding

Scale-Up Effects On BOM/BOP

Key considerations

Controlling variability in BOM and BOP:

- Adds to cost, complexity
- Impacts quality control, inventory readiness, parts tracking, supplier contracts

Parts planning:

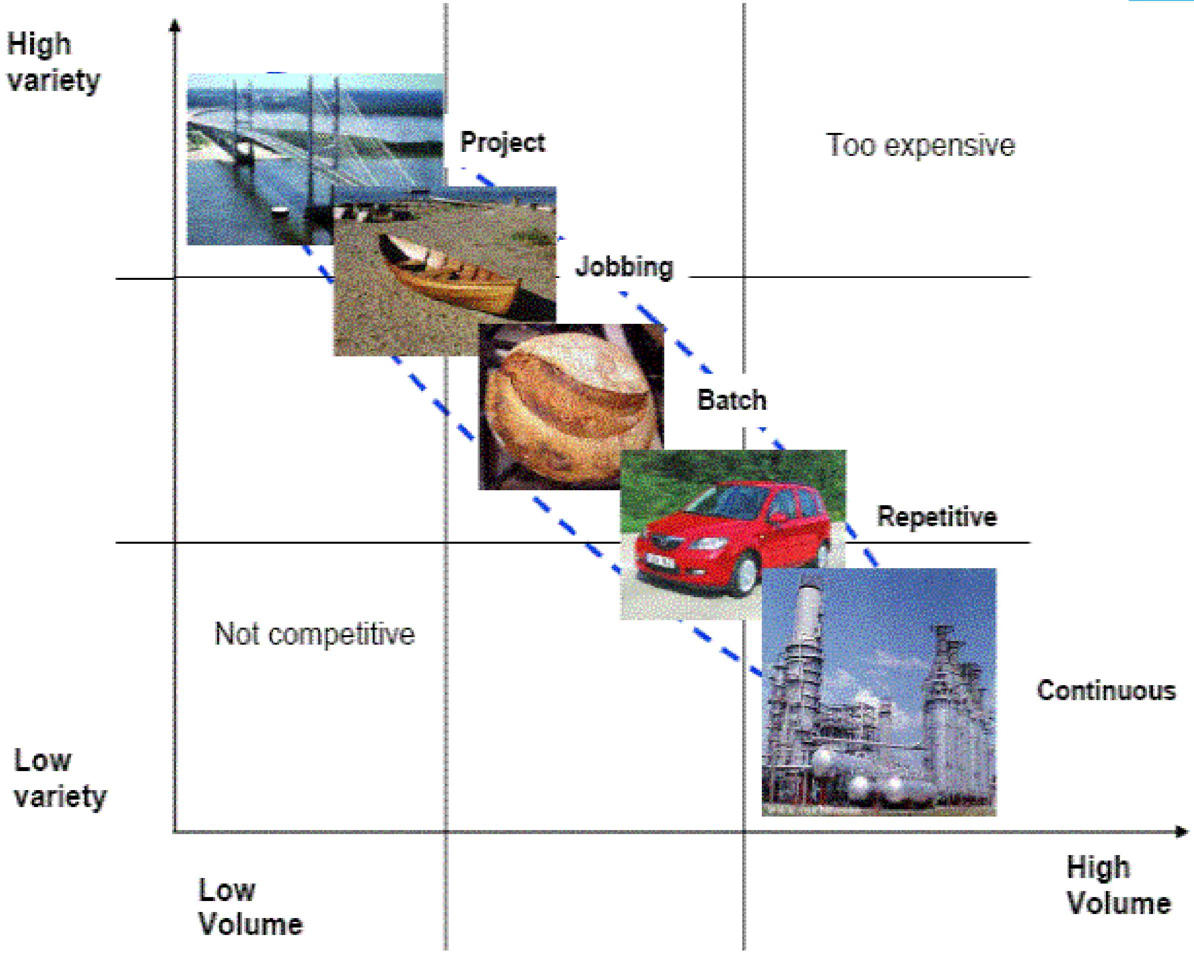
- Consider a parts tracking system (for inventory ordering/control and quality traceability)
- Highly recommend a plan for each part!

Process documentation:

- Work flow process mapping (value stream mapping)
- ISO process documentation

Scale-Up Effects On BOM/BOP

Summary



Resources

- General molding resource guide
  http://www.plasticmoulding.ca/techniques/compression_moulding.htm

List Of Terms

In glossary

- **BOM – Bill of Materials** is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product.
- **BOP – Bill of Process** is a best practices template for production comprised of detailed plans explaining the manufacturing processes for a particular product. Within these plans resides in-depth information on machinery, plant resources, equipment layout, configurations, tools, and instructions.
- **Engineering Drawings** are a type of technical drawing is used to fully and clearly define requirements for engineered items.
- **Assembly Drawings** show how different parts go together, identify those parts by number, and have a parts list,
- **Routing Sheet** in a manufacturing or production unit defines the exact process by which a product is to be manufactured or a service is to be delivered.
- **Product Hierarchy** is the decomposition of a product showing the relationship between parts. This is used in conjunction with the BOM which additionally shows all critical product information including lists the raw materials, assemblies, components, parts and the quantities of each needed to manufacture a product.
- **LLC - Low-Level Coding** refers to the lowest level code of the item used in BOM. The low level code is registered to each item, and is used to perform a level-by-level explosion.
- **BOM Processor** is data management system that organizes the specifications of product assemblies and structures used in manufacturing and related industries. Essential component in most commercial software packages; maintains the BOM and automatically assigns Lowest-Level Coding (LLCs) — The BOM processor is essential for products with large BOMs (e.g., automobiles include approximately 30,000 components)
- **Process Planning** is a plan of how your parts will be produced, what machines to use and in what order, to achieve the correct tolerances etc. It involves strategic decisions and careful analysis with production *engineers* and expertise in order to plan and adapt the production of every single component.

List Of Terms

In glossary (cont.)

- **Orthographic Projection** is a means of representing three-dimensional objects in two dimensions.
- **Dimensional Tolerances** is the permissible limit or limits of variation in: a physical dimension; a measured value or physical property of a material, manufactured object, system, or service; other measured values (such as temperature, humidity, etc.); in engineering and safety, a physical distance or space (tolerance); in mechanical engineering the space (such as between a bolt and a nut or a hole, etc.)
- **Component Level Design** involves the selection, maintenance, design and construction of smaller parts for a larger machine/assembly. This includes selecting, qualifying, approving, documentation, and managing the purchasing of components and direct material required to produce an end product.
- Component engineering also involves product lifecycle management plan when a component is going to be obsolete or to analyze the form–fit–functionality changes in the component.
- **Geometric Tolerances** (GD&T) is a system for defining and communicating engineering tolerances. It uses a symbolic language on engineering drawings and computer-generated three-dimensional solid models that explicitly describes nominal geometry and its allowable variation.
- **Material Properties** is an intensive, often quantitative, property of some material
- **Mechanical Properties** is the response of the material to force and load.
- **Physical Properties** is any property that is measurable, whose value describes a state of a physical system. Physical properties are often referred to as observables.
- **Thermal Properties** is the reaction of the material in the presence of heat or cold.
- **Electrical Properties** is the ability of a material to transmit, store, or impede electricity.
- **Optical Properties** is the ability of the material to transmit, reflect, or absorb light.
- **Environmental Properties** are the ability of the material to maintain performance in its application environment.

List Of Terms

In glossary (cont.)

- **Hardness** is the resistance of a material to indentation.
- **Young's Modulus** also known as the elastic modulus, is a measure of the stiffness of a solid material.
- **Stainless Steel** is a steel alloy with a minimum of 10.5% chromium content by mass. Stainless steel is notable for its corrosion resistance, and it is widely used for food handling and cutlery among many other applications.
- **Polycarbonates** are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent.
- **Resin Transfer Moulding (RTM)** is an increasingly common form of molding, using liquid composites.
- **Vacuum Assisted Resin Transfer Molding (VARTM)** is a closed mold, out of autoclave (OOA) composite manufacturing process.
- **Pultrusion** is a continuous process for manufacture of composite materials with constant crosssection.
- **Hand lay-Up** is a molding process where fiber reinforcements are placed by hand then wet with resin.
- **Compression Molding** is a method of molding in which the molding material, generally preheated, is first placed in an open, heated mould cavity.