Chapter 3: Product Configuration and Design for Function / Design for Manufacturing, Prototyping and Product Architecture

Repeated Questions:

1. Design for Maintenance:

- **Q.** Write importance of designing for maintenance. **(SUMMER 2022; SUMMER 2023; SUMMER 2024 OR; WINTER 2024)**

Answer:

- **Reduces Life-Cycle Cost:** Easy maintenance lowers repair cost, downtime cost, and total cost of ownership for the customer.
- **Increases Product Availability:** Quick and simple maintenance reduces equipment downtime and improves productivity.
- **Improves Safety:** Design for safe access, isolation, and replacement of worn parts reduces maintenance accidents.
- **Extends Product Life:** Replaceable modules, standard parts, and easy servicing allow the product to remain functional for a longer period.
- **Improves Customer Satisfaction:** Products that are easy to service create trust, reduce frustration, and improve brand reputation.
- **Supports Sustainability:** Repairable products reduce waste and support reuse, remanufacturing, and circular economy practices.

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2. Prototyping and 3D Printing:

- **Q.** Explain virtual prototyping with an example of CAD. **(SUMMER 2022; WINTER 2024; SUMMER 2026, 4 Marks OR)**

Answer:

Definition:

Virtual prototyping is the use of computer-based models and simulation to test, analyse, and refine a product design before physical prototypes are built.

- **CAD Model Creation:** A 3D CAD model is prepared with geometry, dimensions, materials, and assembly details.
- **Simulation and Analysis:** The model is tested using CAE tools such as stress analysis, thermal analysis, motion simulation, and fluid flow analysis.
- **Design Iteration:** Results are used to modify the design virtually, reducing the need for repeated physical prototypes.
- **Example:** In CAD software, a car suspension arm can be modelled and analysed for stress and fatigue under different loads. The design is optimised virtually before a physical prototype is manufactured.
- **Advantages:** Saves time and cost, improves design accuracy, allows rapid iteration, and supports design for manufacturing and assembly.

- **Q.** Write advantages of 3D Printing. **(SUMMER 2022 OR; SUMMER 2024, 4 Marks; WINTER 2024 OR; WINTER 2025, 3 Marks OR)**

Answer:

- **Rapid Prototyping:** Physical models can be produced directly from CAD data in a short time.
- **Complex Geometry:** Internal channels, lattice structures, and intricate shapes that are difficult by conventional machining can be manufactured.
- **Customisation:** Each part can be individually customised without additional tooling cost.

- **Tooling Reduction:** Eliminates or reduces the need for moulds, dies, and fixtures for prototype production.
- **Material Efficiency:** Additive deposition uses material only where required, reducing waste.
- **Design Freedom:** Supports lightweight design, topology optimisation, and functional integration.
- **Faster Design Validation:** Enables quick testing of fit, form, and function before production.

- **Q.** Explain free-form fabrication method (additive manufacturing) as a prototyping technique. **(WINTER 2022, 7 Marks OR; SUMMER 2023, 7 Marks; SUMMER 2024 OR; SUMMER 2026, 7 Marks OR)**

Answer:

Definition:

Free-form fabrication, also called additive manufacturing or 3D printing, is a prototyping technique in which a three-dimensional object is built layer by layer directly from a digital CAD model.

Diagram Description: A CAD model is converted to STL format, sliced into thin layers, and then built on a 3D printer platform by depositing or solidifying material layer by layer.

Process Steps:

CAD Model Creation:

- A 3D solid model of the prototype is created in CAD software.

Conversion to STL Format:

- The CAD model is converted into STL format, which represents the surface as triangulated facets.

Slicing:

- The STL file is sliced into thin horizontal layers using slicing software.
- Tool path and process parameters are generated.

Layer-by-Layer Fabrication:

- The 3D printer builds the part by depositing molten polymer, curing resin, or sintering powder layer by layer.

Post-Processing:

- Support material is removed.
- Surface finishing, curing, or heat treatment is carried out if required.

Validation and Testing:

- The prototype is tested for fit, form, function, and assembly.

Common Methods:

- **FDM:** Fused Deposition Modelling — molten thermoplastic filament is deposited layer by layer.
- **SLA:** Stereolithography — liquid photopolymer resin is cured by laser.
- **SLS:** Selective Laser Sintering — powder material is fused by laser.

Advantages:

- Fast prototyping
- Complex geometry possible
- No or low tooling required
- Customisation possible
- Material waste is low
- Good for design validation

3. Product Modularity:

- **Q.** What is product modularity? Explain various types of product modularity. **(WINTER 2022; SUMMER 2024; WINTER 2024 OR; SUMMER 2025, 7 Marks)**

Answer:

Definition:

Product modularity is a design approach in which a product is decomposed into independent modules that can be designed, manufactured, assembled, and replaced separately while functioning together as a complete product.

Diagram Description: A product shown as a central platform with separately attachable modules such as power module, control module, and interface module connected through standard interfaces.

Types of Product Modularity:

Component-Swapping Modularity:

- Different modules can be substituted to create product variants.
- **Example:** Different camera modules in a smartphone.

Component-Sharing Modularity:

- The same module is used across multiple products.
- **Example:** Same battery pack used in different power tools.

Fabricate-to-Fit Modularity:

- Modules are customised to fit a specific product or customer requirement.
- **Example:** Customised seat module for a commercial vehicle.

Bus Modularity:

- Modules connect to a common bus or platform through standard interfaces.
- **Example:** Expansion cards connected to a computer motherboard.

Sectional Modularity:

- Modules are arranged in a chain or section, and each module performs a distinct function.
- **Example:** Modular conveyor sections.

Mix Modularity:

- A combination of different modularity types is used in the same product.
- **Example:** A modular kitchen using standard cabinets, customised panels, and shared fittings.

Advantages:

- Product variety with fewer components
- Easier assembly and service
- Lower inventory cost
- Faster design changes
- Better upgradability and reparability

4. Design for Assembly:

- **Q.** How is the design for assembly (DFA) methodology important to minimize the cost of assembly? Explain briefly. **(WINTER 2022; WINTER 2024 OR)**

Answer:

- **Reduces Part Count:** Eliminating unnecessary parts directly reduces assembly operations, handling, and inventory cost.
- **Simplifies Handling:** Designing parts with symmetry, chamfers, and easy orientation reduces handling time and risk of damage.
- **Simplifies Insertion and Fastening:** Self-aligning features, snap fits, and integrated fasteners reduce assembly time and errors.
- **Minimises Reorientation:** Designing for top-down assembly and minimum part orientation reduces handling and fixture requirements.
- **Standardises Parts and Tools:** Standard fasteners and common tools reduce tooling cost and operator confusion.
- **Designs for Automation:** DFA guidelines make parts suitable for automatic feeding, insertion, and inspection, lowering labour cost.
- **Improves Quality:** Fewer parts and simpler operations reduce assembly defects, rework, and warranty cost.

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5. Product Specifications and Function Analysis:

- **Q.** Enlist the steps required to target the product specifications. **(WINTER 2022, 3 Marks; WINTER 2024, 3 Marks)**

Answer:

- **Prepare the List of Metrics:** Convert customer needs into measurable technical metrics.
- **Collect Competitive Benchmarking Information:** Measure and compare competing products against each metric.
- **Set Ideal and Marginally Acceptable Target Values:** Define the best possible value and the minimum acceptable value for each metric.
- **Reflect on the Results and the Process:** Review target values for consistency, feasibility, and alignment with customer needs.
- **Finalise Target Specifications:** Document final target specifications for use in concept development and detailed design.

- **Q.** Describe the function analysis approach used for product development. **(WINTER 2022, 7 Marks OR; SUMMER 2026, 7 Marks)**

Answer:

Definition:

Function analysis is a systematic method of identifying, describing, and evaluating the functions of a product or its components to improve value, reduce cost, and satisfy customer needs.

Identify the Product and Its Purpose:

- Define the overall function of the product in verb-noun form.
- **Example:** “Transmit torque,” “contain liquid,” “support load.”

Decompose the Product into Functions:

- Break the product into sub-functions and components.
- Prepare a function tree or function diagram.

Classify Functions:

- **Basic functions:** Essential for the product to work.
- **Secondary functions:** Support the basic function.
- **Unnecessary functions:** Do not add value and should be eliminated.

Assign Cost and Worth to Functions:

- Estimate the cost of performing each function.
- Determine the worth of each function to the customer.

Compare Cost with Worth:

- Identify functions where cost exceeds worth.
- These are priority areas for value improvement.

Generate Alternatives:

- Develop alternative ways to perform high-cost or low-value functions.
- Use brainstorming, value engineering, and TRIZ.

Evaluate and Select Alternatives:

- Assess alternatives for feasibility, cost, quality, and customer value.
- Select the best solution for each function.

Implement and Review:

- Incorporate selected improvements into the design.
- Review the product for improved value and reduced unnecessary cost.

Other Important Questions:

1. Design for Maintenance:

- **Q.** Enlist the different types of maintenance operations in the industry. **(SUMMER 2025, 3 Marks OR)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** What is design for maintainability of the product? **(WINTER 2022, 3 Marks OR)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** Prepare the list of steps involved in design for product maintenance. **(SUMMER 2026, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

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2. Function Analysis and Value:

- **Q.** What is functional analysis in engineering? **(SUMMER 2022, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** What is a Function Family Tree (FFT)? Explain it. **(SUMMER 2025, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** Explain the types of functions of any product. **(SUMMER 2025, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** Definition: (i) Political Value and Social Value (ii) Plan value and Time value. **(WINTER 2023, 4 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

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3. Product Modularity and Architecture:

- **Q.** What is Module heuristics? State its applications. **(WINTER 2025, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** Name type of Product Modularity. **(SUMMER 2022, 4 Marks OR)**

Answer:

Definition:

Product modularity is a design approach in which a product is decomposed into independent modules that can be designed, manufactured, assembled, and replaced separately while functioning together as a complete product.

Diagram Description: A product shown as a central platform with separately attachable modules such as power module, control module, and interface module connected through standard interfaces.

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Advantages:

- Product variety with fewer components
- Easier assembly and service
- Lower inventory cost
- Faster design changes
- Better upgradability and reparability

- **Q.** Which are the steps to establish the product architecture? **(SUMMER 2023, 3 Marks OR)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** List the steps to establish the product architecture. **(SUMMER 2024, 3 Marks)**

Answer:

[Answer not found in the answer chat – to be added]

- **Q.** Define the product architecture and its types. **(SUMMER 2026, 3 Marks OR)**

Answer:

[Answer not found in the answer chat – to be added]

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4. Design for Manufacturing and Assembly:

- **Q.** Explain guidelines for evaluation of the Overall Assembly. **(SUMMER 2022, 7 Marks)**

Answer:

Evaluate Part Count:

- Check whether each part is necessary.
- Combine or eliminate parts that do not perform a distinct function.

Evaluate Handling and Orientation:

- Assess symmetry, size, weight, and ease of gripping.
- Minimise the need for reorientation during assembly.

Evaluate Insertion and Alignment:

- Check for chamfers, guides, and self-aligning features.
- Avoid tight tolerances and difficult insertions.

Evaluate Fastening Method:

- Prefer snap fits, integral hinges, and self-locating features.
- Reduce screws, nuts, washers, and separate fasteners.

Evaluate Assembly Sequence:

- Ensure a clear top-down assembly sequence.
- Avoid hidden or difficult-to-reach operations.

Evaluate Tooling and Fixtures:

- Minimise special tools and fixtures.
- Use standard tools and common access directions.

Evaluate Automation Suitability:

- Check whether parts can be fed, oriented, and inserted automatically.
- Avoid flexible, tangled, or unstable parts.

Evaluate Quality and Serviceability:

- Identify possible assembly errors and design mistake-proofing features.
- Ensure modules and wear parts can be serviced easily.

- **Q.** Explain the General Guideline for optimizing the number of parts in the design. **(SUMMER 2025, 7 Marks OR)**

Answer:

Eliminate Unnecessary Parts:

- Remove parts that do not perform a necessary function.
- **Question every part:** "Does it move? Does it need a different material? Must it be separate for assembly or service?"

Combine Functions into One Part:

- Design a single part to perform multiple functions.
- **Example:** Combining a bracket and a heat shield into one component.

Integrate Fasteners:

- Use snap fits, press fits, or integral locking features instead of separate screws and clips.

Use Standard and Common Parts:

- Standardise fasteners, bearings, and connectors across the product family.
- Reduces part variety and inventory cost.

Design Multi-Functional Components:

- Use a part for structural support, alignment, and sealing simultaneously where feasible.

Avoid Separate Brackets and Connectors:

- Integrate mounting features directly into moulded or cast parts.

Consider Manufacturing Process Capability:

- Use processes such as injection moulding, die casting, or additive manufacturing that can produce complex integrated shapes.

Review Service and Assembly Requirements:

- Keep parts separate only when required for wear, maintenance, material incompatibility, or assembly access.

- **Q.** How are the manufacturing costs of a product decided in DFM methodology? Explain in detail. **(WINTER 2022, 7 Marks)**

Answer:

Definition:

In Design for Manufacturing (DFM), manufacturing cost is estimated and controlled by analysing material, process, tooling, assembly, quality, and volume-related cost drivers during design.

Material Cost:

- Determined by material type, quantity, availability, and scrap/waste.
- DFM prefers standard, easily available, and cost-effective materials.

Processing Cost:

- Depends on manufacturing process selected, cycle time, machine hour rate, labour, and energy.
- DFM selects processes that match part complexity and production volume.

Tooling and Equipment Cost:

- Includes moulds, dies, fixtures, jigs, and special equipment.

- DFM reduces tooling cost by simplifying geometry and using standard tooling where possible.

Assembly Cost:

- Depends on number of parts, handling, insertion, fastening, and testing operations.
- DFA guidelines reduce assembly time and labour cost.

Quality and Rework Cost:

- Poor manufacturability causes defects, rework, and rejection.
- DFM improves process capability and reduces variation.

Overhead Cost:

- Includes supervision, inspection, inventory, and facility cost.
- Simplified designs reduce inventory and inspection burden.

Volume Effect:

- High volume reduces per-unit tooling and processing cost.
- DFM aligns design and process selection with expected production volume.

Should-Cost Estimation:

- Cost is built up from material, process, tooling, assembly, and overhead.
- Supplier quotations and benchmarking are used to validate the estimate.

- **Q.** Describe the evaluation techniques of design for manufacturing methodology. **(SUMMER 2026)**

Answer:

DFM Guidelines Checklist:

- Evaluate the design against standard DFM rules such as simple geometry, standard materials, minimum tolerances, and easy fixturing.

Part Count and DFA Analysis:

- Use DFA methods such as Boothroyd–Dewhurst analysis to evaluate part count, handling, insertion, and assembly time.

Should-Cost Analysis:

- Estimate material, processing, tooling, assembly, and overhead cost from first principles.
- Compare estimated cost with target cost and supplier quotes.

Manufacturability Review:

- Cross-functional review by design, manufacturing, quality, and supplier teams.
- Identify features that are difficult to machine, mould, cast, or assemble.

Process Capability Analysis:

- Check whether tolerances and surface requirements are within the capability of the selected process.

Prototyping and Pilot Production:

- Build prototypes and pilot batches to validate manufacturing feasibility and cost.

Value Engineering:

- Compare function cost with function worth and eliminate unnecessary cost.

Supplier Feedback:

- Obtain early supplier input on material availability, tooling, process, and cost.

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5. 3D Printing:

- **Q.** Enlist the advantages of 3D printing. **(SUMMER 2025, 4 Marks)**

Answer:

- **Rapid Prototyping:** Physical models can be produced directly from CAD data in a short time.
- **Complex Geometry:** Internal channels, lattice structures, and intricate shapes that are difficult by conventional machining can be manufactured.
- **Customisation:** Each part can be individually customised without additional tooling cost.
- **Tooling Reduction:** Eliminates or reduces the need for moulds, dies, and fixtures for prototype production.
- **Material Efficiency:** Additive deposition uses material only where required, reducing waste.
- **Design Freedom:** Supports lightweight design, topology optimisation, and functional integration.
- **Faster Design Validation:** Enables quick testing of fit, form, and function before production.

- **Q.** Briefly describe 3-D printing technology. Write its advantages. **(SUMMER 2023, 7 Marks OR)**

Answer:

Definition:

3D printing, or additive manufacturing, is a process of building a three-dimensional object layer by layer from a digital CAD model.

Diagram Description: A CAD model is sliced into layers and built on a 3D printer platform by depositing or solidifying material layer by layer, followed by post-processing.

Process:

- **CAD Modelling:** Create a 3D model of the part.
- **STL Conversion:** Convert the model to STL format.
- **Slicing:** Slice the model into thin layers and generate tool paths.
- **Printing:** Build the part layer by layer using polymer, resin, metal, or ceramic.
- **Post-Processing:** Remove supports, cure, finish, or heat-treat the part.

Common Technologies:

- **FDM:** Fused Deposition Modelling
- **SLA:** Stereolithography
- **SLS:** Selective Laser Sintering

Advantages:

- **Rapid Prototyping:** Fast production of physical models from CAD.
- **Complex Geometry:** Internal channels, lattice structures, and organic shapes are possible.
- **Customisation:** Each part can be customised without extra tooling.
- **Low Tooling Requirement:** No mould or die is needed for prototypes.
- **Material Efficiency:** Material is used only where required.
- **Design Freedom:** Supports lightweight and topology-optimised designs.
- **Faster Design Validation:** Fit, form, and function can be tested quickly.
- **Distributed Manufacturing:** Parts can be produced at or near the point of use.

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6. Reverse Engineering and Industrial Design:

- **Q.** Explain briefly the concept of reverse engineering for product development. **(WINTER 2022, 4 Marks)**

Answer:

Definition:

Reverse engineering is the systematic process of analysing an existing product to understand its design, materials, construction, and working principle for product development or improvement.

Product Selection and Disassembly:

- Select the product and disassemble it systematically.
- Document components, dimensions, and assembly sequence.

Technical Analysis:

- Analyse materials, manufacturing processes, tolerances, and mechanisms.
- Prepare bill of materials and component specifications.

Design Reconstruction:

- Create CAD models and technical drawings from measured data.
- Understand the design intent and identify strengths and weaknesses.

Redesign and Improvement:

- Modify the design to reduce cost, improve performance, or add features.
- Use insights for benchmarking, competitor analysis, and legacy product support.

- **Q.** How is industrial design important to a product? Also write its aesthetic needs. **(WINTER 2023, 7 Marks)**

Answer:

Definition:

Industrial design is the professional practice of designing products to improve their appearance, usability, ergonomics, manufacturability, and market appeal.

Importance of Industrial Design:

- **Improves Market Appeal:** Attractive products attract customers and create a strong first impression.
- **Creates Product Differentiation:** Design helps the product stand out in a competitive market.
- **Improves Usability:** Ergonomic design makes the product easier, safer, and more comfortable to use.
- **Strengthens Brand Identity:** Consistent design language builds brand recognition and loyalty.
- **Supports Manufacturing:** Design considers materials, processes, and assembly for cost-effective production.
- **Enhances Customer Experience:** Good design improves satisfaction, emotional connection, and perceived value.
- **Addresses Safety and Sustainability:** Design can improve safety, accessibility, and environmental performance.

Aesthetic Needs:

- **Form and Shape:** Pleasing proportions, harmony, and visual balance.
- **Colour:** Appropriate colour scheme and finish.
- **Texture:** Surface feel and visual texture.
- **Style:** Alignment with current trends and target customer taste.
- **Sensory Appeal:** Sound, touch, and visual comfort.
- **Cultural and Social Fit:** Design that respects user culture and social expectations.

- **Simplicity and Elegance:** Clean, uncluttered, and easy-to-understand design.

Chapter 4: Product Architecture and Virtual Product Prototyping

Repeated Questions:

None identified.

Other Important Questions:

1. Product Modularity:

- **Q.** What is product modularity? Explain the modularity design in brief. **(WINTER 2025, 3 Marks)**

Answer:

Definition:

Product modularity is a design approach in which a product is decomposed into independent modules that can be designed, manufactured, assembled, and replaced separately while functioning together as a complete product.

Modularity Design (Brief):

- **Functional Decomposition:** The product is divided into distinct functional modules (e.g., power, control, interface) connected through standardised interfaces.
- **Module Interchangeability:** Modules can be swapped or shared across product variants, enabling product variety with fewer unique components.
- **Design Benefits:** Modularity simplifies assembly, reduces inventory, enables easier service and upgrades, and supports parallel development of modules.
- **Common Types:** Component-swapping modularity (substitute modules), component-sharing modularity (same module across products), bus modularity (modules on a common platform), and sectional modularity (modules in a chain).
