Introduction to the Topic

Once the functional/user requirements have been identified and the various design concepts needed to achieve these outcomes have been systematically considered, it becomes important to develop robust products at the lowest possible cost.

Achieving the necessary functional outcomes at the best possible cost is a major determining factor in the selection of the final design concept.

Learning Outcomes

Upon successful completion of this Topic you will be able to:

- discuss how costs are used to identify the price of a product review
- apply the Value Engineering method
- discuss the Design for Manufacture and Assembly process
- discuss the Design for Service approach
- discuss the Design for Environment procedure as applied to product design.

Session 5.1 Value Management (VA/VE)

In the past price was largely determined by the profit the manufacturer ‘deserved’ and added to the basic manufacturing cost - represented by the following equation, namely:

\[ \text{PRICE} = \text{COST} + \text{PROFIT} \]

But in today’s competitive marketplace nobody ‘deserves’ a profit and the current formula has changed to:

\[ \text{PROFIT} = \text{PRICE} - \text{COST} \]

Today the price is determined by the marketplace and the profit is derived only after the fully burdened manufacturing costs have been determined. Obviously the best way of achieving a good profit is by lowering manufacturing costs.
Value Analysis and Value Engineering (VA/VE) are methods that have been successfully deployed to help select designs that present maximum function at the lowest cost.

Developed in the 1940s at the General Electric Corp by Larry Miles, Value Analysis (VA) and Value Engineering (VE) are techniques used to optimize designs by improving Value.

In both approaches several types of Value can be considered, namely:

- **Cost Value**: the total cost of a product/process
- **Esteem Value**: properties that make ownership desirable or give status
- **Use Value**: what the product will do
- **Real Value**: the market value of the product to the customer

The formula used to derive value is given as:

\[
\text{VALUE} = \frac{\text{FUNCTION}}{\text{COST}}
\]

In this relationship the value of a product/process is increased by increasing the functions and/or by reducing costs. Typically VE is more effective than VA because it can be applied earlier in the PD cycle - before the design is completed. But both techniques are primarily aimed at reducing costs by generating the necessary functions at the lowest cost and by reducing waste.

The following steps are typically applied during a VA/VE analysis, namely:

**Phase 1 - Information**
- Identify the aim and scope of the project.
- Gather all necessary information.
- Identify a suitable cross-functional team (PDT).

**Phase 2 - Function**
- Generate a list of functions.
- Develop a FAST diagram.
- Select opportunities for improvement.

**Phase 3 – Creation**
- Expand on the selected functions.
- Brainstorm for opportunities.

**Phase 4 – Evaluation**
• List the advantages and disadvantages for each proposal.
• Quantify the benefits of each.

**Phase 5 – Implementation**

• Develop an action plan for the successful implementation strategy including release and monitoring procedures

In the VA/VE approach it is important to include all relevant functions for assessment. Dr Noriaki Kano identified three fundamental categories of functions, namely:

• *Basic Functions*: these relate directly to the fundamental operation of the product and are not often discussed by the customer – unless violated

• *Performance Functions*: relating directly to the way the product/process is perceived to operate - one dimensional customer demands.

• *Excitement Function*: relating to features/functions that are a pleasant surprise to the customer

All of these functions are important and the optimum design should satisfy these at the lowest possible cost.

For the sake of the VA/VE analysis all functions should be:

• succinctly described using an action verb followed by a noun wherever possible

• measurable (and include units) wherever possible

• at least verifiable, if not measurable.

The costs that are used to compare different design alternatives should reflect the fully burdened costs wherever possible. These can be derived through the use of techniques like Activity Based Costing (ABC). That is, these costs should include all direct as well as indirect costs (including transport, storage, handling, preparing, packaging, delivery, warranty, equipment, administration costs, etc.). But these are not always easy to identify at the ‘conceptual’ design stages.

One particular advantage of the VA/VE is that it can be applied equally successfully to products, processes and procedures. But in more recent times another technique DFM/DFA has been developed to
specifically help the manufacturing sector identify accurate manufacturing costs at the early design stages.

Session 5.2: Design for Manufacture/Design for Assembly

The introduction of digital technologies to the manufacturing sector throughout the 1970s highlighted the opportunity for improved productivity through automation. But early attempts to automate were not always successful and a number of research programs were set in motion to determine what factors would determine the successful application of automation technologies. Research programs conducted around the world, (notably at U Mass, Hitachi, Westinghouse, Prime Lucas etc.) were focused on identifying what factors determine manufacturing feasibility.

Having identified assembly as the weakest link in the quest for automation feasibility (for the same reasons that it affects the efficiency of manual assembly), Boothroyd Dewhurst Inc. (BDI) developed the concept of Design for Assembly (DFA).

The main aims of DFA are to:

- simplify designs by minimizing the number of separate component parts and processes
- design component parts and processes for easy and mistakeproof assembly.

Complexity is yet another relevant factor used to rate the cost and robustness (reliability) of competitive designs. Typically complex designs, exhibit a large number of component parts and interfaces thereby increasing the number of possibilities for things to go wrong as well as the overall cost of the product. Assembly time and the number of separate component parts are key contributors to complexity, and Design for Assembly (DFA) has been successfully used to reduce costs.

In the general DFA approach, both fasteners and connectors are regarded as secondary processes that can be theoretically replaced by integral fastening methods or eliminated by combining parts. They are therefore seen as potential candidates for elimination. All remaining components are evaluated for minimum part count through the application of three fundamental criteria, namely:
'Does the part need to be separate because of relative motion, or because of specific material properties, or because combination with other parts would prohibit assembly or disassembly?'.

Where the response to all three criteria is ‘No’, then the part is considered as a candidate for elimination or combination with other parts. All remaining parts are analysed for manual handling and insertion difficulties so that they can be improved through appropriate design actions using the following design guidelines, namely:

- minimize the number of parts
- minimize the number of separate fasteners
- minimize the number of assembly surfaces and directions
- assemble from top down
- improve assembly access and visibility
- maximize part symmetry
- optimize part handling
- provide for integral location and locking of parts
- drive towards modular design.

In particular the BDI technique applies manual assembly times as a metric to compare different design levels. These times are generated from empirical time and motion studies for both manual handling and insertion processes. One added benefit of this approach is that these times are relatively accurate and they can be used to design the production processes almost at the same time as the parts are being designed.

The success of DFA led to the development of a similar technique that could provide relatively accurate costing estimates for the fabrication of component parts at the earliest possible stages of the PD cycle. Design for Manufacture (DFM) was later developed (in support of DFA) to provide further cost analysis for the basic fabrication (manufacturing) process. Software programmes enable the PDT to ask ‘What if?’ questions for different fabrication methods at the concept design stages and use the responses to make informed decisions to help optimize “manufacturability”.

In particular, the BDI Concurrent Costing software is capable of analysing more than 20 different manufacturing processes. In this way tooling costs, material costs, processing costs, cycle times etc are
identified with a minimum number of inputs and before rapid prototypes are manufactured.

A number of ‘manufacturability’ guidelines are used to help focus the direction of the PDT, namely:

- simplify the shape and design of each part
- minimize machining operations
- allow for adequate hold down for secondary operations
- design for ‘near net’ shaping processes
- use standard stock and standard components wherever possible
- standardize features
- specify the most liberal tolerances and surface finishes possible
- avoid special finishes and coatings
- use free machining alloys.

Session 5.3: Design for Service (DFS)

Following the success of DFM and DFA, manufacturers realized the need to include serviceability to the list of important design criteria. DFA already addresses serviceability in its pursuit of minimum part count, modular design and simple processes (i.e. will combination of the part adversely affect assembly or disassembly of other parts?). Generally a good DFA design will typically exhibit superior disassembly characteristics than one that has not undergone a DFA analysis. However Design for Service (DFS) is used to estimate the time and cost needed to carry out specific service tasks on products, with the primary aim of identifying difficulties that may arise during this process so that design action can be taken to improve ‘serviceability’.

As with DFA, time estimates and a serviceability index are generated for the systematic disassembly and reassembly of component parts. In the BDI approach, a DFA analysis is used as a surrogate for the DFS analysis where assembly operations are automatically reversed to provide the disassembly data.

By using the disassembly times and reassembly times in conjunction with the cost of the replacement parts and operations, a service index can be derived (DFS Index) to compare alternative design proposals.

\[
\text{DFS Index} = \frac{\text{Csi} \times 100}{\text{Csi} + \text{Cso}}
\]
Where: Csi is the cost of the service items

    Cso is the cost of the service operations.

The larger the service index, the better the serviceability of the product and the more expensive the part, the greater the justification for service.

Conversely service tasks that require lengthy diagnostic procedures, special equipment and are difficult to reassemble will generate a low service index. The aim of DFS is to identify areas that may present service difficulties and to revise the design to reduce operation times.

Some design guidelines that can be applied to improve serviceability are:

- improve access and visibility for service parts
- minimize the number of manipulations and operations
- ensure parts are robust and able to be serviced with our breaking
- allow adequate clearance for tooling
- consider the use of modules
- design for ease of testing
- design for high reliability.

Session 5.4: Introduction to Design for Environment (DFE)

Note: This section provides an introduction to an approach that is particularly suited for mechanical designs. Topic 9, written by Mr Allan McLay, is a separate unit on Design for Disassembly/Environment will be delivered at a designated time as a supplement to this element.

In more recent times the effects on the environment of pollutants and by-products from the manufacturing industry have received a high degree of urgency while increased attention has also been focused on the appropriate disposal of products at the end of their life cycle. Apart from their adverse impact on the environment, generating pollutants, using toxic materials, disposing of spent products, recycling etc. adds considerable cost – most of which has been typically borne by governments and society as a whole. Today many governments have
legislated to make manufacturers responsible for the full end of life cycle of their products.

Once again, the overall environmental imprint made by a product is predominantly determined at the early concept stages of the product development cycle. The objective of Design for Environment (DFE) is to minimize the impact of adverse environmental effects of a product by design.

Certainly the most important way of reducing the environmental impact of a product is by making it as efficiently as possible in the first place. Reducing wasteful operations, eliminating redundancies, minimizing complexity, reducing weight etc are a few of the basic design guidelines previous covered through good DFM/DFA practices. Further, the need to minimize the use of toxic materials and the ability to recycle products are now well accepted within the paradigms of the current social norm. Many organizations have policies and procedures set in place to ensure that designers comply with their environmental requirements as well as those imposed by governments.

Some general guidelines that should always be considered are:

- optimize the product design – minimize size, weight, complexity etc.
- maximize recyclability and reuse – use commonly recycled materials
- maximize the life of the product – design the product to achieve a maximum lifespan
- minimize the use of toxic materials – avoid toxic materials, use clear labelling etc.
- minimize the quantity and variety of materials – use a ‘mono material’ approach to simplify disassembly
- optimize manufacturing processes – avoid processes that are high in energy consumption
- maximize serviceability – design for easy access for testing or removal of serviceable parts
- optimize product distribution logistics – minimize packaging, select clean and reusable forms of packaging.

As well as the need to embrace a comprehensive environmental policy at an organizational level and the generic application of DFE guidelines as previously mentioned, a more rigorous approach to DFE
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requires a detailed analysis of component parts and processes at the design stage to enable designers to make well informed trade-offs at the design stage.

Working together with their DFA process, BDI has developed DFE software that provides a progress review of the financial and environmental impacts of each part/process during the disassembly process.

Based on the disassembly sequence of a design, two main analyses are performed concurrently:

- the financial assessment for disassembly, reuse, recycle and disposal is displayed for each stage of the disassembly process
- the environmental assessment is displayed step by step throughout the disassembly process resulting from the initial manufacture to the end of life condition.

The environmental impact is determined using a metric called ‘MET Points’ developed by TNO and based on the European Life Cycle Assessment. In simple terms, the MET points equate to the material scarcity factors (M), the energy related green-house effects (E), and toxicity on humans and environment (T). This is a simplified approach used to help designers without ecological backgrounds to consider environmental factors in their designs.

In this approach the MET analysis (green curve) combined with the financial analysis (blue curve) reflects the financial and environmental impact of the product life cycle. This can be used at the design stage to develop designs alternatives that are easier and more cost effective to disassemble.

![Figure 5.1 Graphs reflecting the disassembly costs and associated ecological impact during the recycling of an electric motor. Source: DFE Software from BDI 2005](image-url)
Activity 5 A

Design optimizing

Reading:

- Please refer to the bibliography at the start of the programme and read the articles referring to DFMA, DFM and/or DFX. The most important of these is Boothroyd, Dewhurst and Knight, (2001), *Product Design for Manufacture and Assembly*, CRC, ISBN 0 8247 0584 X

Websites:

- [www.npd-solutions.com/dfmguidelines.html](http://www.npd-solutions.com/dfmguidelines.html)
- [http://calpoly.edu/](http://calpoly.edu/)
- [www.dfm.com](http://www.dfm.com)
- [www.value-eng.org](http://www.value-eng.org)

Activity:

1. In reference to the 4-ring binder discussed in Topic 3, how would you apply the VA/VE technique to improve the design?
2. Prepare yourself for a discuss on how you would apply the DFMA technique to do the same
3. How would you compare the two techniques for optimizing designs?

Study:

- Concurrent Costing examples using software, which will be demonstrated during lectures.
- Application exercises, including those using software and charts.
Summary and Outcome Checklist

This Topic introduced you to design optimisation.

Tick the box for each statement with which you agree:

- I can discuss how costs are used to identify the price of a product review.
- I can apply the Value Engineering method.
- I can discuss the Design for Manufacture and Assembly process.
- I can discuss the Design for Service approach.
- I can discuss the Design for Environment procedure as applied to product design.

Assessment

Assessment for this Topic will be included in Assignment 1.
Assessment for Session 5.4 is the purpose of Assignment 2.