

Design for Manufacturing and Assembly (DFMA) Analysis and Design Improvements of Over-the-Head ABC Headphone

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Abstract – Over-the-head headphones are a type of audio electronic gadget to have a better and safer sound experience. This paper presents a study of Design for Manufacture and Assembly (DFMA) principles applied to an existing overhead headphone to identify opportunities to simplify its design and improve assembly efficiency. The product was examined through component analysis, functional evaluation, and review of its sub-assemblies. DFA principles were used to assess the existing component structure and identify possibilities for reducing unnecessary parts and simplifying assembly operations. The study further examined major components from a Design for Manufacturing (DFM) perspective, based on their materials, functions, design features, and manufacturing processes. The study also examines whether reducing the number of components necessarily results in lower manufacturing cost, considering factors such as product complexity, assembly requirements, materials, and manufacturing methods. The analysis demonstrates how DFMA principles can support improved product design, manufacturability, assembly, serviceability, and overall design efficiency.

Keywords: Part Count Reduction, Assembly Optimization, Product Simplification, Design for Manufacture and Assembly (DFMA), Design for Assembly (DFA), Design for Manufacture (DFM), Product Design, Cost Reduction, Design Efficiency, Product Redesign, Innovation

1. INTRODUCTION

In the present competitive world, companies develop great products by reducing their life cycle and lowering costs. Design for Manufacture and Assembly (DFMA) is an important approach in product development that considers manufacturing and assembly requirements during the design process [1]. Design for Assembly (DFA) focuses on simplifying product structure, reducing unnecessary components, minimizing fastening requirements, and improving assembly efficiency, while Design for Manufacture (DFM) considers the suitability of component designs, materials, and manufacturing processes [2]. The present study applies these principles to an existing ABC over-the-head headphone selected for detailed product evaluation. Being an electronic gadget, a headphone consists of both mechanical and electronic components within a compact,

foldable structure and includes features such as adjustable head support, rotating ear cups, wireless connectivity, control buttons, speaker drivers, a battery, and a printed circuit board. The product consists of several individual components and sub-assemblies that work together to provide its intended functions. Therefore, it provides a suitable case for examining the relationship between product structure, component design, manufacturing, and assembly. The study begins with an examination of the product's functions, specifications, component structure, and sub-assemblies. The existing product is dismantled and studied through photographs, drawings, dimensional observations, and component-level analysis. These observations provide the basis for evaluating the existing design using DFMA principles and identifying areas where the product structure and assembly process can be improved.

The DFA study evaluates the headphone assembly with emphasis on part count, fasteners, assembly sequence, component orientation, and joining methods. Opportunities for simplifying the assembly are identified by examining individual sub-assemblies and their part interactions. The DFM study further examines selected components with respect to their functions, materials, design features, and manufacturing processes. Most of the selected structural components are manufactured using injection moulding, with features such as ribs, bosses, draft angles, fillets, lettering, and surface finish considered as part of the manufacturing evaluation. Based on the analysis, design improvements are proposed to simplify the product and improve its manufacturability and assembly efficiency. These include reducing unwanted components, optimizing standard parts, replacing selected components with integrated features, and incorporating snap-fit arrangements where suitable. The modified design is then compared with the existing product structure to determine the effect of the proposed changes. The study demonstrates the practical application of DFMA principles to an existing consumer electronic product and highlights how systematic evaluation of product structure can support part-count reduction, simplified assembly, improved manufacturability, and more efficient product design.

1.1 Objectives of this Study

DFMA techniques can be adopted for any physical product where assembly is involved; this technique can be adopted and analyzed either during product development or on a finished product; there is always room for improvement irrespective of how simple a product structure is.

1. Analysis and market study for existing similar product designs.
2. Discuss the function and specifications of selected over-the-head headphones.
3. Discuss the guidelines for Part Optimization
4. Critique product designs for ease of assembly and manufacture
5. Analyze product structure, sub-assemblies, part designs, and standard parts used
6. Examine the Design for Assembly principles and guidelines used
7. Propose improvements in product assembly using DFA principles by using:
 - Dismantle the product and study the product assembly structure with respect to DFA
 - Provide pictures, drawings, and dimensions to support the study, analysis, and proposals.
8. DFM analysis for the custom parts from the selected product in DFA Part and carry out the following:
 - Describe the design and function of the custom parts.
 - Analyze the material and manufacturing process used for part development.
 - Examine the Design for Manufacturing principles and guidelines used in the existing part.
 - Propose improvements in component design using DFM principles
9. Compare the existing product with the improved product assembly and conclude on the efficiency using DFMA.

2. METHODOLOGY

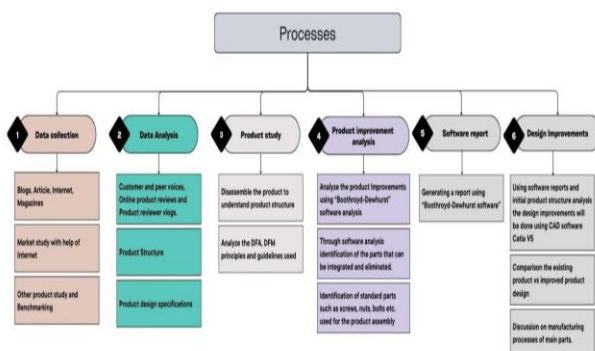


Fig -1: Methodology followed for the study

2.1 Design for Assembly and Manufacturing

Design for Manufacturing and Assembly (DFMA) is a design philosophy used by designers when a reduction in part count, a reduction in assembly time, or a simplification of subassemblies is desired. It can be used in any environment regardless of how complex the part is or how technologically advanced the environment might be [3]. It is gaining popularity where manufacturing costs are a concern. DFMA encourages concurrent engineering during product design so that the product qualities reside with both designers and the other stakeholders in developing the product. Fig -1 shows the methodology followed for this study.

The product development methodologies such as Design for Manufacturing and Assembly have shown repeatedly over the years that most of the cost of a product is fixed during design. The best time to find cost reductions is during the design stage or product development, and not during manufacturing. The sub-branches of this are Design for Assembly (DFA) and Design for Manufacturing (DFM), where DFA means designing the product for the ease of its assembly, thus reducing confusion, and DFM means designing the parts or components of the product for the ease of its manufacturing in terms of materials or process. In the modern product development cycle, DFMA plays a crucial role. Fig. 2 below shows the flow chart where DFMA is incorporated in the traditional workflow [3].

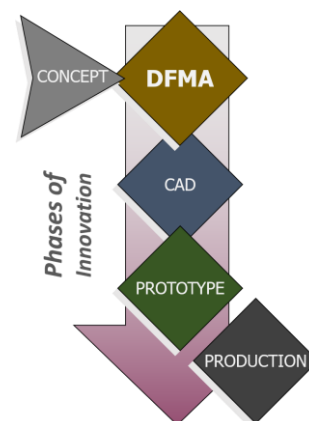


Fig -2: Product development stages by integrating DFMA

3. OVER-THE-HEAD HEADPHONE

An over-the-head headphone is an electronic audio gadget placed over the ears and worn over the head for support; to get a better sound experience out of it, the sound comes from the amplifier directly fed into the ear. Headphones are an end product made from several components assembled in a particular sequence; headphones, which are also known as earphones, are designed to let a single user listen to an audio source privately, in contrast to a loudspeaker with enhanced grip while using it. It consists of electroacoustic transducers, which convert electrical signals to corresponding sound

waves at a particular audible frequency. Headphones are directly connected to an electrical signal source to receive signals and transform to corresponding audio (sound). This paper deals with the study of DFMA analysis applied to the headphone assembly in terms of product assembly and part manufacturing. Below, Fig. 3 depicts the methods followed for the DFMA analysis of an over-the-head ABC headphone.

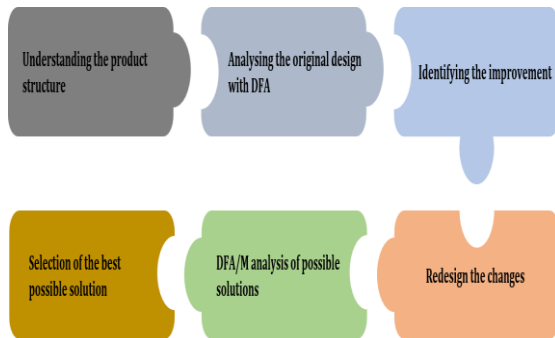


Fig -3: Methods involved in DFMA analysis of Headphone assembly

3.1 Function

Headphones are designed to provide portable and convenient audio playback while maintaining comfortable interaction during travel and everyday use. The primary functions include wireless connectivity with audio devices through Bluetooth, for functions such as sound reproduction, volume adjustment, track selection, and user control through integrated buttons. The headband and ear-cup assemblies are designed to adjust to different demographics, while cushioning improves comfort during prolonged use. The folding mechanism further helps to simplify the anatomy of the headphone, enabling convenient storage and transportation. Below Table. 1 shows the specifications of the ABC headphone.

The functional operation is based on the conversion of electrical signals into audible sound through the interaction of the amplifier, voice coil, magnet, and diaphragm. Audio signals received through Bluetooth are processed and amplified before reaching the speaker drivers, where electromagnetic interaction causes the diaphragm to vibrate and generate sound. From a DFMA perspective, the product incorporates injection-moulded plastic housings, cushioned interfaces, fasteners, and mechanical adjustment components. The adjustable headband uses a linear ratchet mechanism for size adaptation, while hinged ear cups provide rotational movement and folding capability, supporting both ergonomic fit and compact storage.

Table -1: Specifications of ABC Over-the-Head Headphone

Category	Specification
General	
Brand	ABC

Headphone Type	Over-the-Head
Headphone Design	On-Ear
Connectivity	Wireless (Bluetooth v5.0)
Compatible Devices	Smartphones, Tablets, Laptops
Built-in Microphone	Yes
Controls	On-Device Controls (Play/Pause, Volume, Call Management)
Foldable/Collapsible	Yes
Material	Plastic with cushioned ear cups and headband
Color Variants	Luscious Black, Aqua Blue, Hazel Beige, etc.
Suitable For	Music, Calls, Travel, Daily Use
Audio Features	
Driver Size	40 mm
Impedance	32Ω
Frequency Response	20Hz–20kHz
Sensitivity	~108 dB
Noise Isolation	Passive Noise Cancellation
Battery & Charging	
Battery Life	Up to 15 hours (at 60% volume)
Charging Time	~2 hours
Charging Interface	Micro USB
Battery Type	Rechargeable Li-Polymer
Additional Features	
Dual Modes	Bluetooth + AUX
Voice Assistant Support	Yes (Google/Siri)
LED Indicators	Yes (Power/Charging/Bluetooth)
Weight	~168 grams

3.2 Product Structure of existing Headphone



Fig -4: ABC Headphone

ABC headphone product image is shown in Fig -4, and its main assembly is segregated into 3 sub-assemblies. The Headband assembly consists of metal reinforcement, cushion, and plastic support; and the LH and RH Ear cup assemblies consist of a shell, housing, driver, buttons, and a microphone in common, and a battery and its support in LH,

and an electronic PCB with an amplifier and control ICs, and USB charging in RH. Fig -5 shows the product structure of the headphone. This headphone has 50 parts in total, of which 5 sets of standard parts, including BOC items, are used. There are mechanical and electronic parts involved in this product. Here, there are a few ways to install the product with screws; thereby, all three sub-assemblies combine to make the final ABC headphone. Fig-6 shows the components of the ABC headphone.

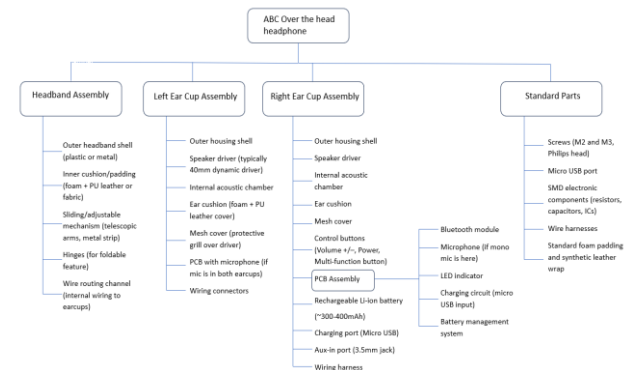


Fig -5: ABC Headphone Product Structure



Fig -6: ABC Headphone Components

3.3 Understanding The Product Structure

The product has individual sub-assemblies and sub-parts for easy maintenance and cleaning. The housing assembly with the ear cup is the main base unit where the headband support assembly shown in Fig. 7 is fitted to form the final assembly. Fasteners are used in a few regions to provide better product structure and appearance. Elements can be easily removed for cleaning and repair needs if required. In the middle extension pillar assembly, the internal extension pillar is arrested by providing a crimping operation on the external pillar top and bottom sides. Snap fits are provided to reduce the number of fasteners.

The parts are primarily manufactured using plastic components, with standard manufacturing processes such as plastic injection molding for the housing and assembly of

electronic components, and some parts incorporate metal elements. Fig. 8 and Fig. 9 depict the LH and RH cushioned ear cup assemblies with rubberized material for comfort. The rest use standard fasteners. Overall, the ABC headphone structure gives a sturdy and aesthetically pleasing appearance to the product. Table 2 illustrates the BOM of the ABC Headphone before DFMA Analysis



Fig -7: Headband assembly of ABC Headphone



Fig -8: LH Ear Cup assembly of ABC Headphone

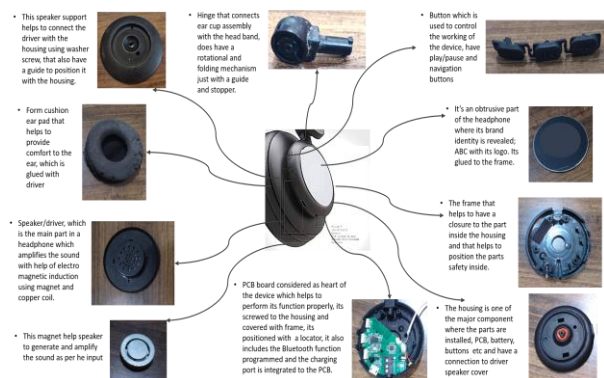
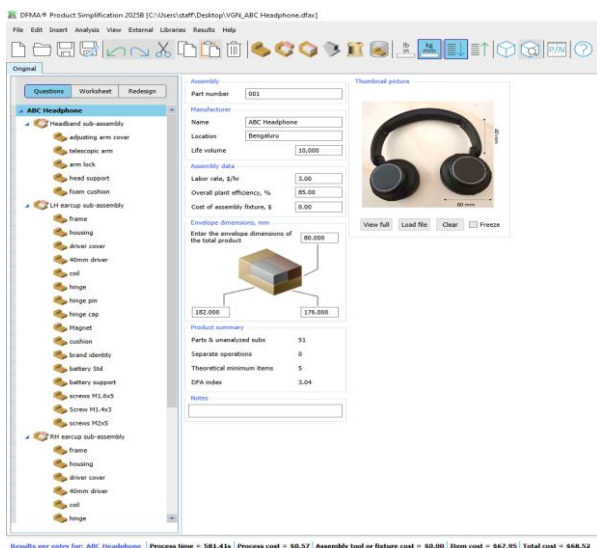


Fig -9: RH Ear Cup assembly of ABC Headphone

Table -2: BOM of ABC Headphone before DFMA Analysis

Part name	Qty
Head band	1
Head cushion	1
Copper coil	2
Frame	2
40mm Driver	2
Cup cushion	2
Driver cover	2
Housing	2
Switches	1
Screws	17
Branding cover	2
Battery	1
Magnet	2
Hinge	2
Hinge cap	2
Hinge Pin	2
PCB	1
Ratchet slider cover	2
Rachet slider	2
wire	3
Slider Lock	2
Battery support	1

4. DFA ANALYSIS OF EXISTING DESIGN


Fig -10: Boothroyd & Dewhurst DFMA Product Simplification software GUI for existing design

4.1 Study with DFA Guidelines

Assembly is one of the important and final stages in manufacturing, and a product will consist of several parts which are to be arranged together to form a final product. DFA product simplification process offers designs with ease of assembly, and if a product contains fewer parts, it takes

less time to assemble, so the cost will be reduced. Parts provided with easy grasp, orientation, and movement will reduce assembly time and cost. DFA also supports improvements in quality, reliability, and reduction in production cost. Fig. 10 shows the Boothroyd & Dewhurst DFMA Product Simplification software GUI for the existing design. In this chapter, various DFA guidelines and principles used in the existing ABC headphone assembly have been analyzed.

Guideline 1: Overall component count should be reduced

The First Measure of assembly efficiency is based on the number of components or sub-assemblies used in the product. Considering the ABC headphone, the number of components can be reduced; mainly, the headband should be removed, and the structure where the ear cup can be hung.

Guideline 2: Make Minimum use of separate fasteners

A good way to reduce component count is by minimizing the use of separate fasteners. In this product, only one star screwdriver is required to disassemble the whole product assembly. All plastic components are assembled with screws that can be easily dismantled by hand using a single tool. But a possibility of reducing unwanted fasteners by swapping them with a snap-fit feature.

Guideline 3: Design the Product with a base component for locating other Components

The product should be designed with a base component for locating other components. Following this guideline, in ABC Headphone, the ear cup assembly uses a single base for assembling other components. The base provides a foundation for consistent component location, fixing, transport, orientation, and strength. All subassemblies follow this guideline in their design to mate through straight-line assembly, all from the same direction.

Guideline 4: Make the assembly sequence efficient

The assembly sequence is also another important guideline to be followed for reducing confusion in parts and sub-assemblies while doing product assembly. An efficient assembly sequence is one that affords assembly with the fewest steps, avoids the risk of damaging components, and avoids creating many disconnected subassemblies to be joined later. These guidelines are embedded in ABC headphone assembly has to start from one part and finish each sub-assembly, and thereby the main assembly.

Guideline 5: Design the components for end-to-end symmetry wherever possible

End-to-end symmetry means that a component can be inserted in the assembly either end first. The operator need not waste time, which will avoid confusion during insertion.

This guideline has been used in ABC Headphone wherever possible and maximizes efficiency while operating each sub-assembly.

Guideline 6: Design the components for symmetry about their axes of insertion wherever possible

This guideline helps analyze assembly labor operations quickly; hence, even non-technical personnel or consumers can understand component assembly when it comes to the axes of part insertion. Here in the ABC headphone, all the assemblies, including the earcup and that of a headband by a hinge, have utilized this guideline wherever possible, which avoids characteristics such as tangling, sharpness, very small size, nesting, flexibility, and slipperiness that make retrieval difficult and having a guide to locate the part and align it.

Guideline 7: Design the components that are not symmetric about their axes of insertion to be clearly asymmetric

When the parts can't be made symmetric, then the design should be obviously asymmetric; the goal with this guideline is to make components that are intended to be inserted only in one way. This guideline is used for the existing design of the ABC Headphone in a few parts that are assembled on an axis and are clearly asymmetric, helping to distinguish LH and RH.

Guideline 8: Design the components to mate through straight-line assembly, all from the same direction

This guideline is intended to minimize the motion of the parts and ease the assembly process, avoiding unwanted actions. Part movement to mate should be in straight-line motions, and they should be in the same direction/axis. Thus, the assembly process will never require reorientation for the assembly. This guideline has been followed in the assembly of the ABC Headphone product design. Parts of the LH and RH earcup assembly and minor parts of the headband assembly also meet this guideline.

Guideline 9: Make use of chamfers, leads and compliance to facilitate insertion and alignment and overcome handling difficulties

As per this guideline, a chamfer should be provided for standard screws in the existing design, which leads to compliance that facilitates insertion and alignment and overcomes handling difficulties. In the ABC Headphone design, chamfers are provided for standard screws and for the parts (i.e., housing, cover), and slots are provided for positioning the screws. These screws are provided to hold the parts rigidly. Here, component characteristics that complicate retrieval, like Tangling, Nesting, flexibility, and slipperiness, are avoided.

Guideline 10: Design the components for a specific type of retrieval, handling, and insertion method

Considering this guideline in an assembly is given for easy disassembly of the parts from the main or sub-assemblies. This avoids confusion when retrieving the parts and instead makes it easier. For the ABC Headphone, this guideline is followed perfectly; RH and LH earcup assemblies have a hinge that connects to the headband that helps the earcup itself to rotate and fold, and is designed with a specific feature for a perfect manual assembly with a specific type of retrieval, handling, and insertion method.

Guideline 11: Do not require the base to be repositioned during the assembly

The assembly is done in a sequential manner, so there's no need to consider this guideline.

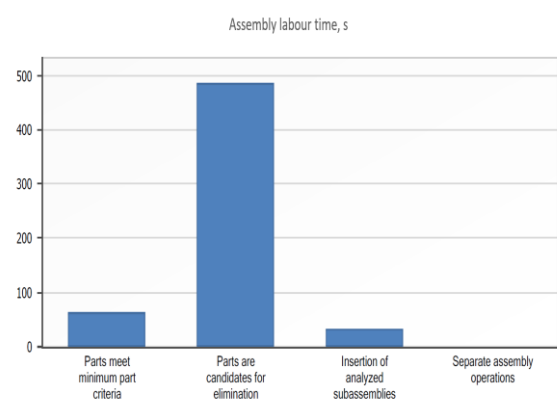
Guideline 12: Avoid component characteristics that complicate the retrieval

The assembly is done in a retrieval manner, so no need to consider this guideline.

4.2 Assembly time and Cost estimation

An analysis of the product using the DFA method of Boothroyd and Dewhurst DFMA analysis gives a result of assembly time and cost estimate for successful assembly of the headphone obtained from the software presented in Chart 1.

Chart -1: Assembly labour time of existing ABC Headphone Assembly



Total assembly process time (s) – 581

5. PROPOSED IMPROVEMENTS OF ABC HEADPHONE ASSEMBLY USING DFA GUIDELINES

DFA principles are further analyzed to identify the improvement possibilities in the existing ABC headphone

assembly. Here are some of the guidelines that can be implemented to make the product more efficient in terms of cost and reliability.

5.1 Part count reduction (Guideline 1)

LH ear cup assembly: In the existing product, the housing and frame are assembled at the hinge with M1.6 x 5 mm (2 No's) and M1.4 x 4 mm (2 No's) screws, without any snap fits. The battery is positioned in a slot and secured with a support with a snap-fit feature, and connected to the speaker cover with a washer screw M2x 5 mm; finally, a branding part is stuck to the housing. This design can be improved by standardizing the screw size to M1.6 x 5 mm (3 No's) and replacing it with a new housing with a snap-fit feature to attach the driver/speaker, and the battery can be positioned in a pocket, which helps to avoid a support, and finally eliminating the branding plate with an embossed logo on the cover. With this improvement, the part count can be reduced from 5 to 1 by removing the frame, speaker cover, logo plate, and battery support.

RH ear cup assembly: In the existing product, the housing and frame are assembled at the hinge with M1.6 x 5 mm (2 No's) and M1.4 x 4 mm (2 No's) screws, which are used without any snap fits; the PCB is positioned with locators and secured with a screw of size M0.8x3 mm (1 No's), and connected to the speaker cover with a washer screw M2x 5 mm; finally, a branding part is stuck to the housing. This design can be improved by standardizing the screw size to M1.6 x 5 mm (3 No's) and replace with a new housing with a snap-fit feature to attach the driver/speaker, and finally eliminating the branding plate with an embossed logo on cover. With this improvement, the part count was reduced from 4 to 1 by removing the frame, logo plate, and speaker cover.

Headband assembly: This assembly, consisting of the adjusting arm cover and telescopic arm, is screwed with M1.6x 4 mm (2 nos. each), and no snap-fit feature is used. This can be replaced with the same screw used in the ear cup assembly, i.e., M1.6x 5 mm, which is more rigid.

Label assembly: In the existing design, the product label or brand logo is separately stamped on an aluminium sheet; as per the improved design, it's being embossed on the housing itself during manufacturing by moulding.

5.2 Make Minimum use of separate fasteners (Guideline 2)

Fasteners: Screws used are of different sizes in this product in 3 different assemblies; with the modified design, it has been brought to a single size for the entire product, which avoids confusion for the assembler and also reduces part count.

5.3 Make the assembly sequence efficient (Guideline 4)

LH ear cup assembly: The left-hand side of the current product consists of audio features, including a 40mm driver and other common parts of a headphone like an acoustic chamber, cushion, mesh, housing shell. However, the main components included are a Li-ion battery and its wiring harness, which come from the PCB on the right side. A part is available to cover the battery using a snap-fit feature. Finally, the hinge connects to the headband. The improved product can be made by removing parts in between, like the speaker cover, housing, and hinge, as the improved product is an over-the-ear headphone, instead of only an outer cover where the driver can be fixed and an outside cushion; mesh is attached to make the LH ear cup assembly ready.

RH ear cup assembly: The right-hand side of the current product consists of features, including a 40mm driver and other common parts of a headphone like an acoustic chamber, cushion, mesh, and 2 housing shells. However, the main components included are a PCB and buttons, along with the wiring harness. PCB is fitted with fasteners; finally, the hinge connects to the headband. The improved product can be made by removing parts in between, like the speaker cover, housing, and hinge; instead, only an outer cover consisting of the PCB and the driver can be fixed to it. Instead of the button, the planned product is made with touch control, but for volume a roller and for power a dedicated slider knob is added, and an outside cushion; mesh is attached to make the RH ear cup assembly ready.

Headband assembly: The ABC headphone is equipped with a headband as it falls under the category of over-the-head headphones, considering DFMA guidelines for part count reduction and enhancing assembly efficiency with the proposed improvements. The headband can be removed to make it an over-the-ear Headphone, with a provision hook structure to hang the earcup on the ear, supported on the postauricular sulcus

5.4 DFA Index (Assembly time efficiency)

Assembly time efficiency is measured in terms of the DFA index. It is defined as a ratio of process time for an ideal product assembly to the process time for an actual product assembly [3]. All parts are analyzed, and the total assembly time for the whole product is added up, as well as the theoretical decision of whether or not the part could be eliminated or integrated. This information is used to calculate an assembly index. The DFA index gives an overall measure of assembly efficiency, and it is expressed as a percentage using the formula (1) given in the equation below [3].

$$\text{DFA Index (\%)} = 100 \times \frac{T_1 + T_2(N_{\min} - 1)}{T_a} \quad (1)$$

Where,

- T_1 - Represents the ideal handling and insertion time for the first necessary part.
- T_2 - Represents the corresponding time for each subsequent Part.
- N_{min} - Theoretical minimum number of necessary parts.
- T_a - Actual assembly time for the product.

The index is a first indication of how well the product is prepared for assembly. Improving the assemblability and DFA index of a product can be done by elimination of "unnecessary" parts and by redesigning parts to be easier to handle and insert. A higher DFA Index indicates greater assembly efficiency and a design that is better optimized for assembly; designers aim to maximize the DFA index for improved product design. The values mentioned in section 5.2 and below are calculated by the software based on the justification of part entries done in Boothroyd and Dewhurst DFA software.

DFA index for existing Headphone assembly = 3.04

6. DFM ANALYSIS OF EXISTING DESIGN

The DFM analysis of the over-the-head headphone considers manufacturability as an integral part of product development rather than as a stage that follows assembly design completion. The existing headphone incorporates several plastic components whose geometry, material selection, and functional requirements directly influence their manufacturing feasibility. The analysis therefore examines the selected components with attention to features such as ribs, bosses, draft angles, surface finish, and lettering, while also considering the relationship between design decisions and subsequent manufacturing requirements. Since the selected components are predominantly produced using high-strength thermoplastics, the suitability of materials such as ABS and polycarbonate is considered in relation to their strength, dimensional stability, impact resistance, surface quality, and moulding characteristics. Table 3 illustrates the part material list of the existing headphone.

The analysis further reflects on how individual component functions influence their manufacturing and construction. The ear-cup assemblies incorporate features such as snap-fit connections, locating bosses, screws, slots, and hinges to support positioning, rigidity, rotation, tilting, and folding. The adjuster arm, telescopic mechanism, speaker cover, frame, and housing similarly combine structural and functional requirements within their respective components. Examining these features through a DFM perspective provides an opportunity to identify how the existing design can be made more suitable for production by considering material behaviour, moulding requirements, component geometry, and assembly-related interfaces at the design stage. Such an approach supports the broader objective of achieving components that can be produced consistently

while retaining their intended functional and structural performance.

Table -3: Parts Material List

Part	Material	Features/Function
Headband (Outer Frame)	ABS plastic (Acrylonitrile Butadiene Styrene)	Lightweight, impact-resistant, and cost-effective for structural parts.
Headband Cushion	PU foam covered with synthetic leather	Offers comfort and aesthetics; PU is cheap and widely used.
Ear Cups (Outer Shell)	ABS plastic (Acrylonitrile Butadiene Styrene)	Strong, impact-resistant, good for enclosing electronics and drivers.
Driver Housing (Inner Shell)	ABS plastic (Acrylonitrile Butadiene Styrene)	Houses the 40mm drivers, requiring moderate strength and precision.
Cushion on Ear Pads	PU foam covered with synthetic leather	Soft and comfortable; "protein leather" mimics natural leather but is synthetic.
Rotating Hinge Mechanism	Reinforced polycarbonate	Durable material with metal for load-bearing hinge movements.
Telescopic Arms (Adjustable)	ABS plastic (Acrylonitrile Butadiene Styrene)	Metal for strength, plastic coating for aesthetics and protection.
Buttons (Power, Volume)	ABS plastic (Acrylonitrile Butadiene Styrene)	ABS for stiffness; silicone for soft-touch buttons (depends on model).
Logo Plate (if present)	Anodized aluminum	Brushed finish with laser-etched or screen-printed logo.
Speaker Drivers (40mm)	Mylar diaphragm, copper coil, neodymium magnet	Standard driver materials for decent sound performance.
Battery (in one earcup)	Standard Parts (BOC)	Rechargeable, lightweight, and compact.
Charging Port (Micro-USB)		Durable material for frequent plugging/unplugging.
Internal PCB & Electronics		Standard PCB material used for controlling the system

Headband (Inner Reinforcement)	to work properly. Provides flexibility and durability for headband tension and size adjustment.
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6.1 Component manufacturing processes

Injection molding is a manufacturing process for producing parts by injecting material into a prepared mold called a die. Injection molding can be performed for materials, including metals, glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers. Material for the part is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the cavity. Fig. 11 illustrates the schematic diagram of the Injection molding machine widely used for manufacturing a variety of parts, from the smallest components to entire plastic panels of cars. This process is used to produce most of the headphone parts. Parts to be injection molded must be carefully designed to support the molding process; the material used for the parts to have the desired shape and features, the mold material, and the properties of the molding machine must all be considered. This makes the design considerations and possibilities support injection molding's versatility.

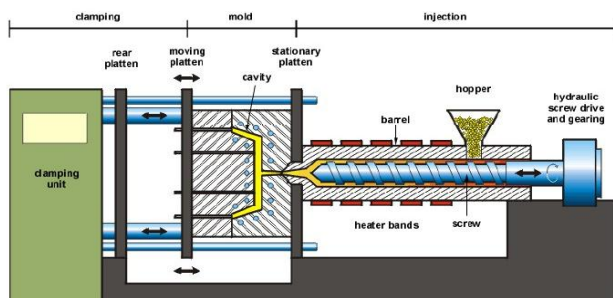


Fig -11: Injection moulding machine schematic diagram [4]
Materials used: ABS (Acrylonitrile Butadiene Styrene), and Polycarbonate

Die Punching is a manufacturing process for producing parts by punching the materials with the help of a prepared die. Fig. 12 illustrates the schematic diagram of Die Punching, which can be performed for different materials, including Aluminum, PU foam, GI steel, Stainless steel, Leather, and other soft materials. They are fed to the bed, and the die made in the desired shape is forced to press on the material, where it gets deformed to the configuration of the die. Die punching is used as an important operation to manufacture a wide variety of parts, from small washers to automotive body parts. In the ABC headphone, this process is used to produce parts like the cushion and brand lettering.

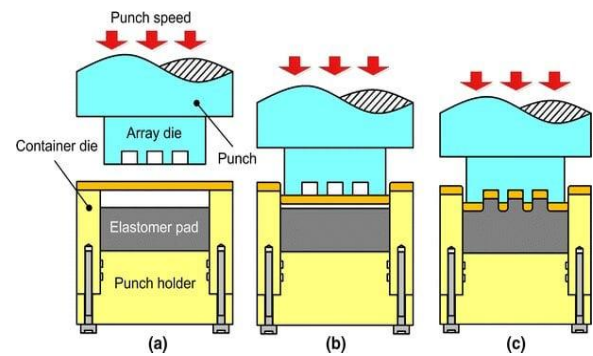


Fig -12: Die punch machine schematic diagram [5]
Materials used: Sheet metal, PU foam

6.2 Study with DFM Principles

Every component design will follow the design for manufacture principle and guidelines that help the manufacturing of the component. Manufacturing considerations can reduce overall development cycle time and cost; DFM focuses on mitigating the manufacturing challenges that migrate to production [6]. These days, all manufacturing companies follow these principles and guidelines. Here we explain the DFM principles and guidelines for components. Although these principles and guidelines initially take more time, they reduce component errors, avoid secondary operations, and save time in the product development process.

Principle 1: Rib design

Ribs are an important aspect of injection-molded parts. They are used when manufacturing each part of this headphone to provide strength. As per DFM guidelines, ribs should be designed in each component of a product. Reinforcing ribs are made thinner than the wall thickness. Rib thickness is set at 40 to 60% of the wall thickness and is no more than 2.5 to 3 times the wall thickness; equally distributed ribs are used in parts like the speaker cover for stiffness. Ribs are perpendicular to the parting line of the mold to permit removal of the part from the mold. Sink marks are visible in the frame where thickness is greater, which can be hidden by grooves or texture opposite to the ribs. Ribs have a draft of 0.5° to 1.5° per side, and radii are 25 to 40 % of wall thickness. Distance between two ribs: 3T minimum. Fig. 13 shows the Ribs implemented in the headphone; this shows that rib guidelines are taken care of while designing this product.

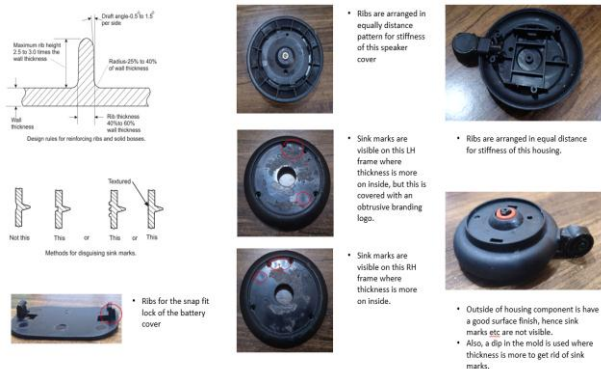


Fig -13: Ribs design implemented in headphone

Principle 2: Bosses design

The Boss design guideline says the Protruding pads are used to provide mounting surfaces or reinforcements around holes. If large bosses are needed, they should be hollow for uniformity of wall thickness. If possible, locate bosses in corners to aid material flow in filling the mold. If a detached boss is necessary, a connecting rib will aid material flow and attach the bosses to the wall with ribs, gussets, and free-standing ribs. Fig. 14 shows the boss design implemented in the headphone; all the guidelines have been followed while designing this product. Possibly, bosses shall be located in corners to aid material flow in filling the mold.

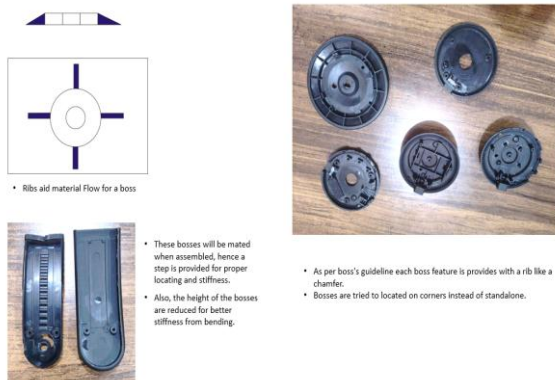


Fig -14: Bosses design implemented in headphone

Principle 3: Material Utilization

In the assembly of this headphone, the material has been used optimally in most of the areas, but still unwanted wastage is visible in a couple of areas. They are extra material deposited during molding due to poor mold design. So, there is a need for design considerations for optimal material utilization with proper mold design. Fig. 15 shows the unwanted material deposition in a few components of this headphone, which needs to be taken care of while redesigning.



- These are the components housing, frames of headphone where material utilization doesn't happen properly.
- We can see bulged portion of materials which is not used in the function of the product.
- Simply these can be considered as material wastage.
- Also, due to this shrink marks are developed on other side.

Fig -15: Unwanted material deposits on headphone parts

Principle 4: Gating

In this product, gating is properly positioned; hence, no traces of gating are visible on most of the components. But still, in a couple of components where an edge gate is used, residue is visible, but there are no traces of weld lines or burnt marks. All round parts are molded with a center gate for equal wall thickness, and no residue is left behind.

Principle 5: Avoid sharp edges in screw assembly

Existing headphone: wherever screws are being used for rigidity, it will matter with the boss feature, and all screws have chamfers in them to guide to the boss during assembly. Also, the bosses' features have the chamfers provided in them. Hence no need to redesign the bosses. Fig. 16 shows consideration of chamfers while designing bosses of this headphone; all the edges have been rounded with a small radius, keeping sharpness apart and making the product smooth.

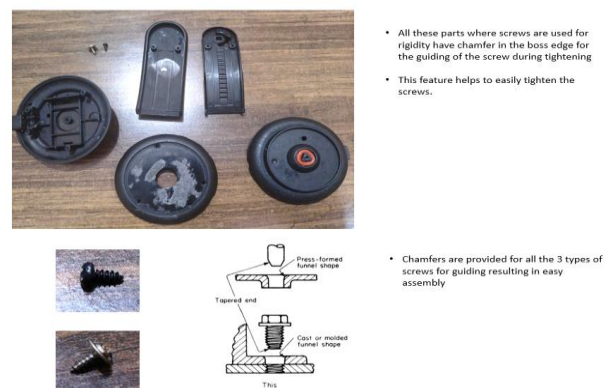


Fig -16: Chamfer on Bosses design

Principle 6: Positioning of Holes properly

ABC headphone uses blind holes in the housing, frame, and speaker cover. As per the guideline, holes are an important feature in injection-molded parts but are a complicating

factor in mold construction and part quality. "Knit" or "weld" lines adjacent to the hole often develop, and flashing may also occur at the edge of the hole. Minimum spacing between two holes or between a hole and a side wall should be one diameter. Also, the hole should be located 3 diameters or more from the edge of the part to avoid stress. Blind holes should not be more than two diameters deep. If the diameter is 1.5 mm or less, one diameter is the maximum practical depth. To increase the depth of a deep blind hole, use steps, which enable a stronger core pin to be employed. Fig. 17 shows the consideration of holes while designing holes for this headphone; all the holes are properly positioned following the guidelines.

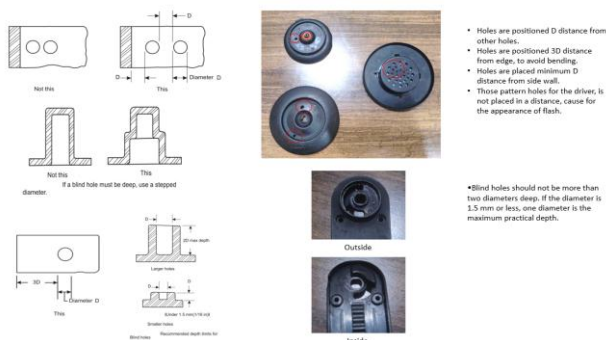
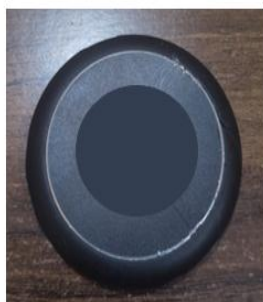


Fig -17: Hole feature on necessary headphone parts

Principle 7: Lettering

The lettering on the part should be raised (i.e., formed by depressed, engraved letters in the mold). It is easier to engrave lettering in a mold cavity than it is to machine away the background. Sometimes it is desired to have depressed letters on the part and to fill them with paint that contrasts with the color of the plastic material. Cavities for filled lettering should be sharp-edged and 0.13 to 0.8 mm wide; they should be one-half as deep as wide and should have a rounded bottom. Fig. 18 shows the brand lettering design on the existing headphone design; they used a separate aluminum blanked sheet for branding. Guidelines were not followed while designing this requirement; hence, it needs to be redesigned and improved.



- Aluminum sheet is used by blanking for the branding, with the logo on it.

Fig -18: Brand logo negative embossed on Aluminum sheet and glued to frame

Principle 7: Surface finish

Surface finish or textures can be molded into the parts. No secondary surface-finishing operations (except plating, hot stamping, or painting, if desired) are necessary. High-gloss finishes are feasible if the mold is highly polished and if molding conditions are correct. However, dull, matte, or textured finishes are preferred to glossy finishes, which tend to highlight sink marks and other surface imperfections. Painting of most thermoplastics is feasible but is not recommended if the color can be molded into the part. The latter approach obviously is more economical and gives superior results. Fig. 19 shows the surface finish on the parts of the headphone; a matte finish is achieved on parts like the housing, arm, and speaker cover.



Fig -19: Surface finish of headphone parts

Principle 8: Flat Surface

In this product, a couple of components do have flat surfaces, which cause irregularities like sink marks, etc. Flat surfaces are somewhat more prone to show irregularities than gently curved surfaces. Since the latter also produce more rigid parts, they are preferred. Fig. 20 shows the sink mark defects on some parts of this headphone due to large flat surfaces and not following the guidelines properly.

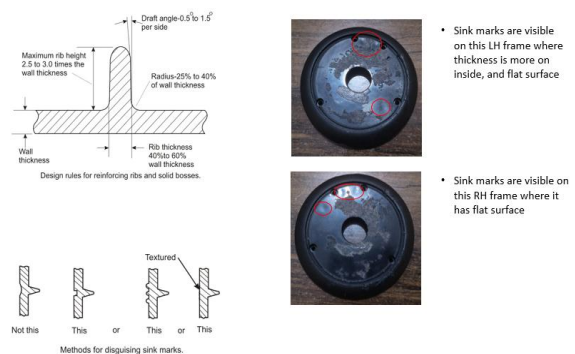


Fig -20: Sink marks on flat surfaces of parts

Principle 9: Parting line

Every injection-molded part shows the effect of the mold parting line, the junction of the two halves of the mold. The part (and the mold) should be designed so that the parting occurs in an area where it does not adversely affect the appearance or function of the part. One easy way to do this is to put the parting line at the edge of the part where there is already a sharp corner. Parting lines should be straight; i.e., the two mold halves should meet in one plane only. This obviously provides more economical mold construction, but it may not be possible if the part design is irregular. If it is not possible to place the parting line at the edge of the part, cleaning parting line flash is facilitated by having a bead or other raised surface at the parting line, as shown in the slide. Deliberately offset cavities are helpful in avoiding appearance defects, which may occur if the two mold halves do not line up properly. Fig. 21 shows the parting line on the parts of this headphone; parting lines are placed properly following the guideline except on the adjusting arm cover. These need to be redesigned and improved.

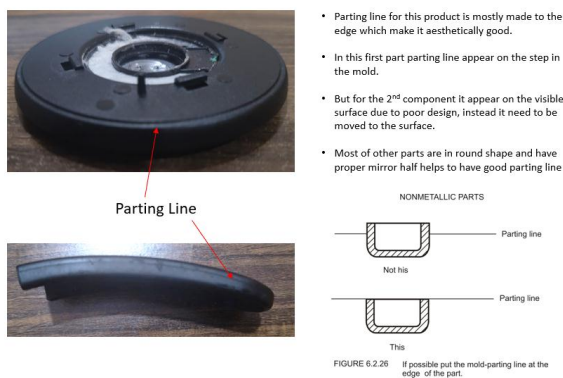


Fig -21: Parting line on headphone components

Principle 10: Draft

In injection-molded parts, draft plays an important role and helps them to eject easily from the die without defects; deep parts require less draft angle than shallow parts. For shallow parts, draft should average $1/2^\circ$ or more; for deep parts, $1/8^\circ$ can often be satisfactory. Textured surfaces require greater draft. It is highly desirable to incorporate some draft in the side walls of injection molded parts to facilitate removal of the part from the mold. Drafts as low as $1/4^\circ$ are often adequate. Fig. 22 shows the draft feature followed while designing the parts of this headphone; draft guidelines are properly followed and implemented while designing the mold for easy ejection/retrieval in the headphone Driver, speaker cover, and adjuster lock.

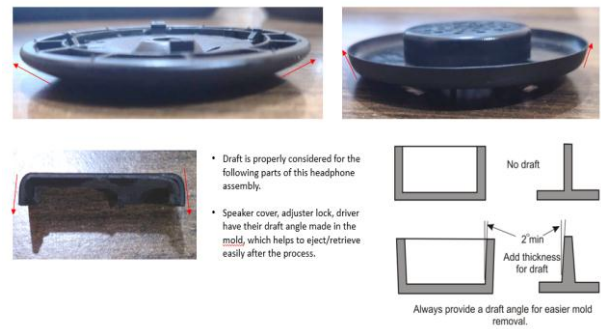


Fig -22: Draft angle on headphone components

Principle 11: Radii and Fillets on corners

The ABC headphone is properly designed with correct radii and fillets; Fig. 23 shows the implementation of radii and fillets on the parts while designing them. As per the guideline, sharp corners should be avoided except at the parting line. They interfere with the smooth flow of material and create possibilities for turbulence with attendant surface defects. Sharp corners also cause stress concentrations in the part that are undesirable from a functional standpoint. Fillets and radii should be as generous as possible. A desirable minimum under any circumstance is 0.5 mm, while 1.0 mm is a preferable minimum if part requirements permit.



Fig -23: Radii and Fillets ensured on headphone parts

7. PROPOSED IMPROVEMENTS OF ABC HEADPHONE ASSEMBLY USING DFM PRINCIPLES

DFM principles are further analyzed to identify the improvement possibilities in the existing ABC headphone assembly. Here are some guidelines that can be implemented to improve manufacturing cost and reliability.

7.1 Refining Brand lettering

A design change was implemented that removes the unwanted aluminum sheet for the brand logo; instead, the brand name is integrated within the manufacturing process by a negative emboss on the die, which reflects as a positive

protrusion on the outer case with the required finish, improving manufacturing time and material utilization and improving efficiency.

7.2 Minimizing flat surfaces

A design change was made focusing on reducing the flat surface when compared to the previous design; also, unwanted thickness is reduced to minimize sink marks on the component. The flat surface is replaced with a slightly curved surface. This helps to reduce defects on the product, hence giving a clean surface.

7.3 Better material utilization

Design changes like proper arrangement of ribs, gussets, and bosses were adopted to remove the unwanted deposit on the component; this helps to better utilize the material in part manufacturing with less wastage and fewer unwanted sink marks on the outer surface. Thus, raw material and scrap consumption costs can be reduced.

8. REDESIGNED PRODUCT

Based on suggestions from the DFA method of Boothroyd and Dewhurst analysis and on DFMA guidelines, product design modifications were identified to improve design efficiency. Analysis and validation with DFMA software showed that considerable changes to the ABC headphone were made by transforming the design from an over-the-head headphone to an on-ear headphone, which helps increase the DFA-Index and thereby improve design efficiency. Fig. 27 depicts Boothroyd & Dewhurst DFMA Product Simplification software GUI for the modified design. The design changes in assembly are detailed in sections 8.2 to 8.5.

8.1 Product Structure of Modified Headphone



Fig -24: Redesigned headphone

The redesigned and modified over-the-ear headphone, as shown in Fig. 24, has two main assemblies, namely the right ear cup and left ear cup assembly. The design improvements helped to standardize fasteners and thereby implement part

count reduction considerably. Fig. 25 shows the product structure of the modified product; considering the final product, a total of 22 parts were reduced wrt. ABC headphone, and improved cost and time. Fig. 26 shows the exploded 3D model illustration of the redesigned product, which has a minimum number of fasteners.

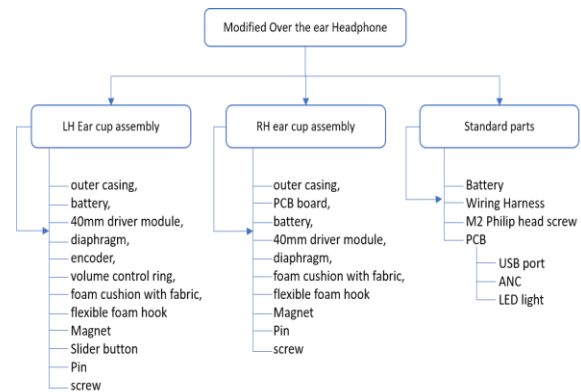


Fig -25: Product structure of redesigned headphone



Fig -26: Exploded view of redesigned headphone

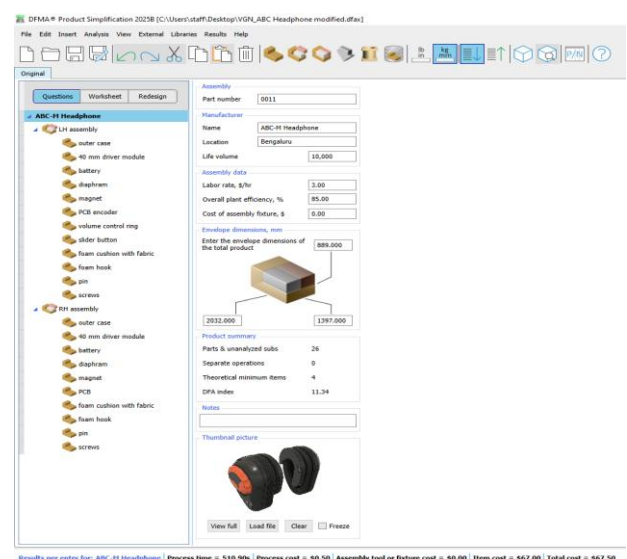


Fig -27: Boothroyd & Dewhurst DFMA Product Simplification software GUI for modified design

8.2 Redesigned LH Ear cup Assembly

The left ear cup sub-assembly is a potential candidate for the headphone final assembly. Major parts of this sub-assembly are an outer casing, battery, a 40mm driver module, diaphragm, magnet, PCB encoder, volume control ring, button, foam cushion with fabric, flexible foam hook, and Pin. In this LH ear cup sub-assembly, fasteners are mostly avoided and replaced with only snap-fit features, except where the hook is fixed to the body and the PCB (encoder) to the case. This brings the sub-assembly to have only 12 individual components and 8 separate primary assembly operations, and 1 secondary assembly operation of adding a fastener to secure the encoder in the product structure. in the product structure. This redesign reduces the excess assembly time and cost, keeping the end function the same.

8.3 Redesigned RH Ear cup Assembly

The Right ear cup sub-assembly is another potential candidate for the headphone final assembly. Major parts of this sub-assembly are outer casing, PCB board, battery, a 40mm driver module, magnet, diaphragm, foam cushion with fabric, flexible foam hook, and Pin. In this RH ear cup sub-assembly, fasteners are used to fasten the PCB to the case, and the hook to the body; all remaining connections are designed with snap-fit features. This allows the sub-assembly to have only 10 individual components and 7 separate primary assembly operations, and 1 secondary assembly operation of adding a fastener to secure the PCB in the product structure. This redesign reduces the excess assembly time and cost, keeping the end function the same.

8.4 Eliminating Headband Assembly

The headband sub-assembly is an important candidate for an over-the-head headphone; after the DFMA analysis redesign changes were considered, it was decided to eliminate the entire headband, and the final product is designed with an over-the-ear design with a foam cushion hook structure that hangs on the ear postauricular sulcus. This redesign brings a new identity to the headphone; this design change from the DFMA analysis helped to meet the core principle of part count reduction and thereby achieve a reduction in assembly cost and time. Chart 2 illustrates the assembly process time for headphone assembly before and after DFMA analysis.

8.5 Standardization of fasteners

Fasteners are considered an important factor in any assembly; following DFMA guidelines, fasteners such as screws play a redundant role in a headphone assembly, and standardization of fasteners can save a considerable amount of assembly process cost. In the existing product assembly, 34% of the part count is fasteners. By considering the DFA improvements in the modified headphone design, standardization of fasteners made the assembly efficient and easy to maintain, which results in a reduction in secondary

assembly processes; thereby, assembly time and cost are reduced.

9. RESULT

After completing dismantling and DFMA analysis of each component of the existing product, data were fed into the DFA and DFM method of Boothroyd and Dewhurst software, which created system-generated results that were exported in various formats. Table 4 illustrates system-generated results of the existing and modified headphone assembly design before and after DFMA in terms of part count, process time, and design efficiency (DFA Index).

Chart -2: Assembly process time for Headphone assembly

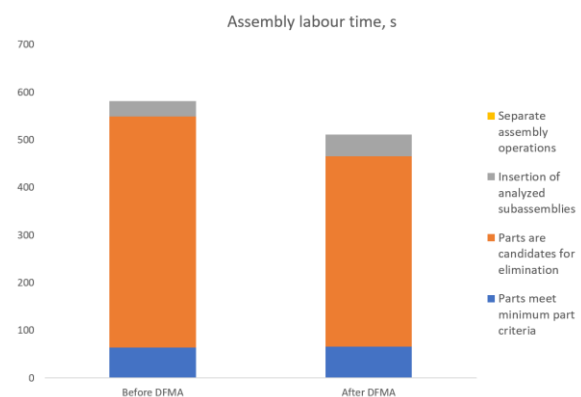


Table -4: Headphone assembly results

	Headphone assembly before DFMA	Headphone assembly before DFMA
Entries including repeats		
Parts meet minimum part criteria	5	4
Parts are candidates for elimination	46	22
Analyzed subassemblies	3	2
Separate assembly operations	0	0
Total entries	54	28
Assembly labour time, s		
Parts meet minimum part criteria	63.41	65.92
Parts are candidates for elimination	485	399
Insertion of analyzed subassemblies	32.61	46.04

Separate assembly operations	0	0
Total assembly labour time	581	511
Design efficiency		
DFA Index	3.04	11.34



Fig -28: Rendering of redesigned headphone

10. CONCLUSION

DFMA study was successfully conducted and applied to the over-the-head headphone for its design and assembly structure analysis. Design for manufacturing and assembly methodologies carry the potential for part count reduction by eliminating or integrating parts, faster new product introduction, assembly process optimization, easier automation, and improved product quality, thereby supporting the reduction of the cost of design and development of the modified headphone assembly. Issues associated with the manufacturing and assembly were taken into consideration at the design stage. To evaluate and optimize the collected information and analysis procedures, discussions were carried out with people having domain expertise. The result of the DFMA analysis proves it effectively supported the concurrent engineering process for excellence. The objectives of this study were ensured and fulfilled with desired quality, cost-effectiveness, lifecycle, and customer satisfaction. A total of **12%** reduction in assembly process time was achieved, resulting in cost reduction. The design efficiency (DFA Index) of headphone assembly was improved by **273%** after successful DFMA analysis. As theory says, introducing and implementing DFMA analysis in the earlier stage of design and development of a new product definitely gives the desired lower cost and higher quality results and supports the business positively.

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REFERENCES

- [1] S. M. Megahed, M. F. Hassan, and Jāmi'at Al-Qāhirah, Current advances in mechanical design and production VII : proceedings of the Seventh Cairo University International MDP Conference ; Cairo-Egypt, February 15-17, 2000. Amsterdam ; New York: Pergamon, 2000.
- [2] P. Dewhurst and G. Boothroyd, "Early cost estimating in product design," Journal of Manufacturing Systems, vol. 7, no. 3, pp. 183-191, Jan. 1988, doi: 10.1016/0278-6125(88)90003-9.
- [3] G. Boothroyd, "Product design for manufacture and assembly," Computer-Aided Design, vol. 26, no. 7, pp. 505-520, July 1994, doi: 10.1016/0010-4485(94)90082-5.
- [4] J. Sun et al., "Polyurethane-rubber punching process for micro-hole arrays," Microsyst. Technol., vol. 23, no. 7, pp. 2943-2950, Jul. 2017, doi: 10.1007/s00542-016-3089-7.
- [5] K. Lakshmi, D. Manamalli, and M. M. Rafiq, "Design of Multimodel based MPC and IMC control schemes applied to injection molding machine," Int. J. Eng. Technol., vol. 3, no. 2, pp. 82-92, Mar. 2014, doi: 10.14419/ijet.v3i2.1844.
- [6] M. O'Driscoll, "Design for manufacture," Journal of Materials Processing Technology, vol. 122, no. 2, pp. 318-321, Mar. 2002, doi: 10.1016/S0924-0136(01)01132-3.

BIOGRAPHIES

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