DFMA and Sustainability Analysis in Product Design

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Abstract — Design for Manufacture and Assembly (DFMA) is a proven and established technique in product design for minimizing the number of components and time of assembly. This approach is particularly important for automotive industry where the design changes frequently happen. The ultimate aim of DFMA is to reduce the cost and maximize the profit of the company without compromising on the quality of the product. DFMA means design the component or system for the *ease of manufacture* and *assembly*. This paper deals about exemplifying the application of DFMA aspects like, re-designing parts and optimize the design to ensure reliability, safety, the minimum number of parts, less time to market and customer satisfaction. This work the emphasizes on exemplifying the implications of DFMA approach on the product design. This is accomplished through few standard case studies. In addition, the DFMA analysis of a component and its impact on environment is also performed. Improvements in the product using DFMA, can lead to significant cost savings and reducing the probability of failures.

Keywords: DFMA**,** Manufacturability, Optimization, Sustainability.

1. INTRODUCTION

The main task of Design engineers is to implement the technical information in solving problems industry and society by optimizing the solution within given restraints. In this direction, the product designer contributes crucially in terms of information, concepts, and skills which will have a major influence on the character of manufactured products, their appeal towards the customer and the total cost-effectiveness. Today every company is aiming at high quality products at low prices and this can only be achieved by *DFMA principles*. DFMA is a blend of two techniques: Design for manufacture (DFM) dealing with the parts fabrication process down to its simplest steps, and Design for Assembly (DFA) dealing with the time and cost of assembling the product. The subject of DFMA originated from the research of automatic assembly by Professor Geoffrey Boothroyd and his graduate student Allan Redford from the work initially carried-out at the University of Salford back in the 60s'. Soon after, a DFMA handbook was developed and major companies like General Electric, Xerox Corporation, Westinghouse Electric, IBM etc. [1, 2].

The DFMA approach focuses mainly on simplifying the design of a component or system with an idea of easing the manufacture and assembly which in turn reduces the cost without compromising on the quality. It does not deal with the enhancing the other aspects of system like its impact on the environment, sustainability, life cycle analysis etc. Thus, when all these factors are considered in the design the approach becomes holistic. Therefore, a number of approaches namely design for sustainability (DFS), design for environment (DFE), design for life cycle have developed.

This paper reviews few research articles demonstrating the application of DFMA approach and examine how it elevated the company's profits. The case studies included are; a design modification of a prosthetic knee for the leg amputees, where the DFMA principles are used to get best design [3]. The next case study is about, the DFMA approach on Pressure vessel design, where many design modifications were implemented and as a result a great decline in Orientation time, welding time and assembly time was observed [4]. The next case study deals with the design simplification of reticle assembly. This was redesigned by the expertise and reduced the number of parts, the manufacturing and Assembly time and total number of operations [1]. In the above

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literature, only DFMA was applied. In order to bring out the significance of sustainability in the product design, a commonly used product, viz., folding chair is taken up in this work. The sustainability analysis indicates that, a system with less environmental impact and efficient in nature can be designed.

2. CASE STUDIES

2.1 CASE STUDY 1: DESIGN OF AN INEXPENSIVE PROSTHETIC KNEE USING DFMA [2]

Prosthetic knee is a boon for the amputees. However, its price is somewhat expensive. The development of an inexpensive prosthetic knee is possible by employing the DFMA approach. The existing prosthetic knee established on Gandhi's design (Old design) has 7 main parts, i.e. lower and upper body, pyramid adapter male and the four linkages (Fig. 1). The main parts were joined by a bearing, shaft, and a snap ring. The prosthetic is connected to the pylon using a clamp attached in the lower body of prosthetic. A design requirement analysis of each part of the prosthetic knee was evaluated. A vital design criterion is that the prosthetic leg must be same as actual leg and be able to carry the loads from day-to-day activities at less cost.

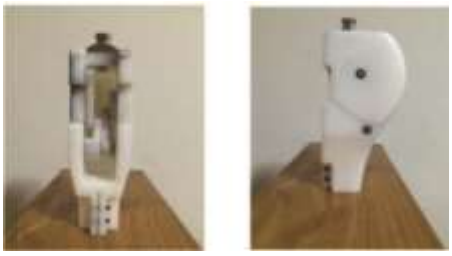

Fig.1 Existing prosthetic knee [2]

The DFA and DFM principles were applied to optimize the design and reduce its cost. For the existing design an assembly time of 453.87 second was needed. The DFA index, which is a measure of assembly efficiency, calculated using Equation 1 is found to be 9.25%. However, the minimum required is above 10% (Table 1).

$$DFA\ Index = {}^{3N_{min}}/_{t_{ma}} \quad (1)$$

Where N_{min} is the minimum number of parts and t_{ma} is total time of assembly.

TABLE 1: COMPARISON BETWEEN THE OLD DESIGN AND NEW DESIGN

	Number of parts	Assembly time, S	DFA Index, %	Cost, $
Without DFMA	14	453.87	9.25	41
With DFMA	16	288.12	16.48	39

After measuring the assembly time, DFM analysis was applied. Injection molding process was used to manufacture the components. The three important parameters in assessing the manufacturability are, mold size, mold cycle time and cost. The cost of manufacturing the main parts are $ 41 with mold fabricating time of 291.38 hours and 22.5 minutes of cycle time. The DFMA analysis indicates that there are opportunities for improving the design with an aim of increasing the DFA index and reducing the cost.

To simplify the fabrication process, the upper body is split in to two parts and its volume was also reduced with a view to reduce mold cycle time. Snap fit is used to join upper and lower parts in order to avoid the use of fasteners. To reduce friction, the dimension of linkages was decreased and the material changed to stainless steel. The modified and detail design is shown in Fig. 2 and 3.

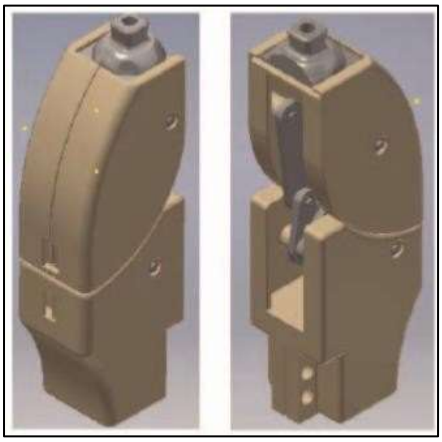

Fig.2 The modified shape of upper body [2]

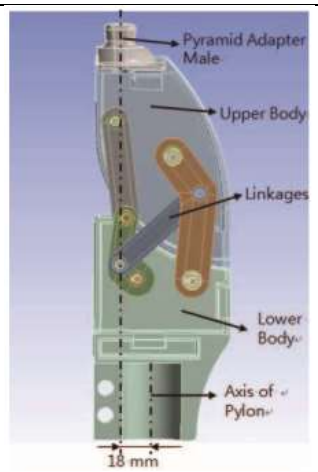

Fig.3 The detailed design [2]

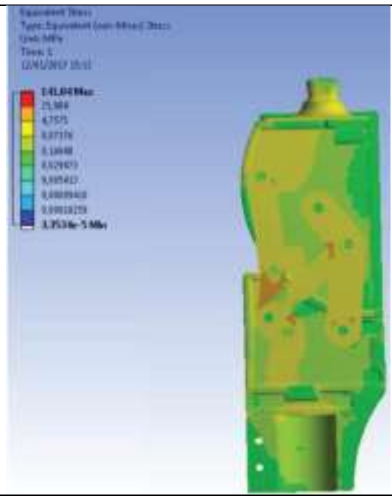

Fig.4 The simulation of modified design [2]

The strength of the prosthetic was analysed using ANSYS Workbench by performing static analysis. And it was proved to that the stress in part of the assembly was less than the yield strength of the stainless steel (Fig. 4).

2.2 CASE STUDY 2: DESIGNING OF PRESSURE VESSEL USING DFMA APPROACH [3]

In this case study, *Boothroyd and Dewhurst method* of Design for Manufacture and Assembly (DFMA) is implemented in designing the pressure vessel. The vessel design, acquired from of the Oil and Gas firm in Malaysia is used (Fig. 5). The pressure vessel was the redesigned to meet the manufacturing and assembly requirements. The approach allows a smaller product development time by minimizing assembly and manufacturing time and the total cost. The application of this method has enhanced the performance and profit of the company. In addition, the *concurrent engineering* method was applied to complete the project, so that any problem in either design or manufacturing of pressure vessel will be solved immediately. The effect of implementing this approach along with DFMA reduced the development time of pressure vessel. In addition, it reduced the rework in manufacturing and assembly process and thereby making it easy and efficient. The pressure vessel model before the application of DFMA, had 33 different components with their individual quantity to fabricate a full pressure vessel.

Fig.5 The pressure vessel model [3]

After implementing DFMA, the total number of components were reduced by 19 and the percentage of reduction is 14.96% as shown in Table 2. The number of components that is reduced is limited because most parts are very critical and their elimination will influence the functionality of the vessel and might lead to the violation of ASME pressure vessel code. However, this has greatly reduced the assembly time, material cost and its handling as shown in Table 3. A marginal increase in the assembly efficiency of the pressure vessel was observed after implementing the DFMA approach

TABLE 2: COMPONENT REDUCTION AFTER IMPLEMENTING DFMA [3]

No	Component	Quantity	
		Existing	Reduction
1	Skirt Gusset Plate	24	12
2	Skirt Vent	3	1
3	Anchor Bolts	12	6
Total Reduction			19

TABLE 3: COMPARISON BETWEEN OLD DESIGN AND NEW DESIGN [3]

Design	**Total Orientation time**	**Total Welding time**	**Total Manual handling time**	**Total Insertion time**	**Total Operation time**
With DFMA	6,325	4,63,360.69	4,70,188.69	1,183.00	4,71,371.69
Without DFMA	6,736	5,12,464.42	5,19,170.42	1,223.00	5,20,393.42
% Reduction	**6.06**	**9.48**	**9.43**	**3.27**	**9.42**

A few design changes implemented are, chamfering of nozzle (Fig. 6), which eases the assembly, reduction of number of anchor bolt holes from 12 to 6 in the compression ring (Fig. 7) decreasing the machining time, and reducing the number of gusset plates from 24 to 12, decreasing the material and handling cost (Fig. 8). Counter-boring of bolt holes in flange help retaining the washer during assembly making material handling easy (Fig. 9). The skirt which originally having 3 components reduced to two with the design modification as shown in Fig. 10. Similarly, on the DFM side, the manual welding process was replaced by Tungsten inert gas welding which reduced the welding to 8 minutes from 30 minutes for welding 30 cm length.

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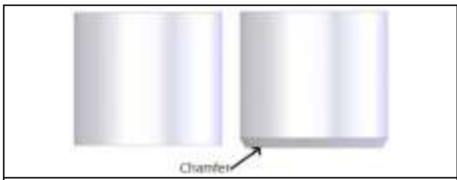

Fig. 6 Chamfering of Nozzle [3]

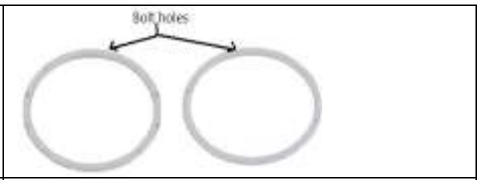

Fig. 7 Reduction of bolt holes [3]


Fig. 8 Reduction of gusset plates [3]

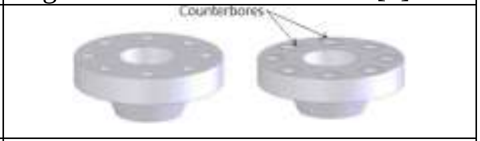

Fig. 9 Counter-boring of bolt holes [3]

Fig.10 The changes on skirt vent model [3]

2.3 CASE STUDY 3: RE-DESIGN ON RETICLE ASSEMBLY USING DFMA [1]

The original reticle assembly meant to carry thermal gunsight which is used to track and view the target at night under confrontational war-field conditions (Fig. 11). During the DFA analysis, it was found that the reorientations and fasteners significantly contributed to the assembly time. In addition to this, special setups for drilling and application of adhesives for fasteners added to assembly time. To alleviate these, the reticle assembly was redesigned, with a view to reduce the number of parts either by removing unnecessary ones or by standardizing the parts to ease the assembly and manufacturing. Several alternatives were proposed and the best possible one was selected. The new design is shown in Fig.12.

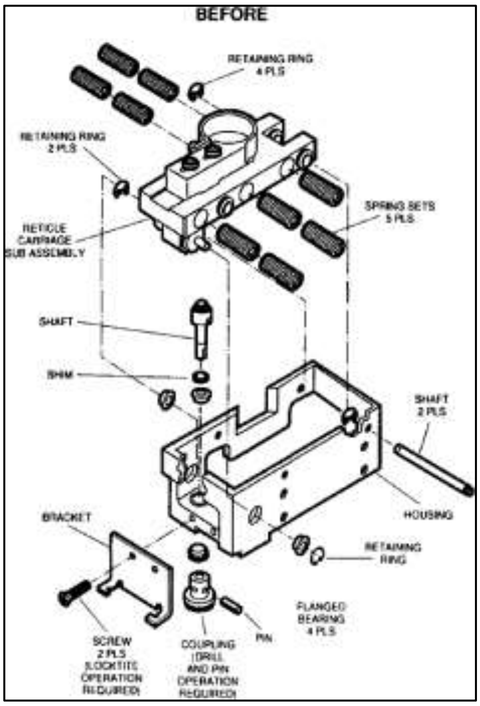

Fig. 11 Original reticle assembly [1]

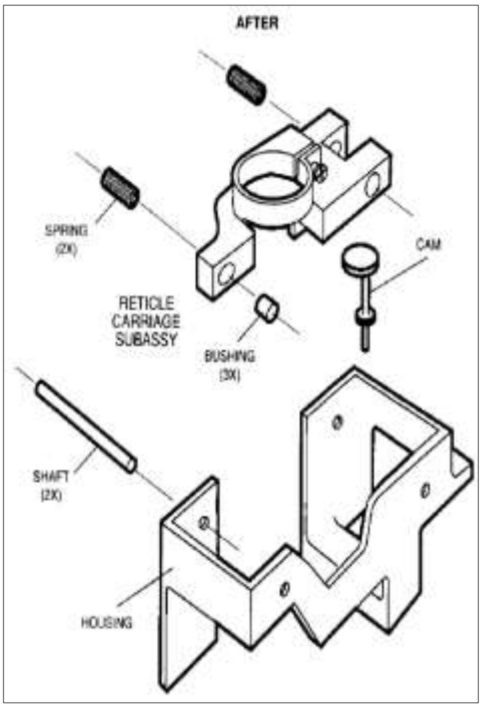

Fig. 12 Redesigned reticle assembly [1]

It may be observed that, the number of different parts were reduced from 24 to only 8 in the new design. The comparison of new and original design given in Table 4.

TABLE 4: APPRAISAL OF ORIGINAL DESIGN AND NEW DESIGN [1]

	Original design	Redesign	Improvement (%)
Assembly time (h)	2.15	0.33	84.7
Number of different parts	24	8	66.7
Total number of parts	47	12	74.5
Total number of operations	58	13	77.6
Metal fabrication time (h)	12.63	3.65	71.1
Weight (lb)	0.48	0.26	45.8

3. SUSTAINABILITY ANALYSIS OF FOLDING CHAIR

A recent global concern is to manufacture products which are environmentally friendly. As a consequence, right from the design phase till the final fabrication of the product, each stage has a profound influence on the cleaner production. In this light, sustainability plays an important role in product design. Due the stringent regulations imposed by the local governments, and increasing demand on eco-friendly products, the industry is forced to incorporate a holistic approach in designing products. Sustainable design is a holistic methodology for producing systems or products which are eco-friendly and harmless. Few aspects of sustainable design are, use of minimal and improved material, design for manufacturability and assembly, design for environment, selection of less hazardous materials, recycle, reuse, and minimize energy consumption [5, 6].

In this context, a sustainability analysis of a simple product is carried out by measuring the environmental impact in terms of total energy consumed, carbon footprint, air acidification etc. The CAD model of existing folding chair is adopted from Ref. 7 (Fig. 13). The design is then modified using DFMA approach to minimize number of parts and the environmental impact (Fig. 14). The existing model is made of three frames and seat which are fabricated using fasteners. The list of parts of existing chair model is given in Table 5.

Fig. 13 CAD model of chair [7]

Fig. 14 Modified chair design

TABLE 5: PARTS OF EXISTING CHAIR DESIGN

Sl.No.	Part Name	Count	Material
1	Frame	3	Steel
2	seat	1	Steel
3	Spreader	2	Steel
4	Foot caps	4	plastic
5	Stability caps	2	plastic
6	Fasteners	20	Cold forged alloy steel
7	Back rest	1	Steel
8	Cross braces	3	Steel
	Total	**36**	

TABLE 6: PARTS OF MODIFIED CHAIR DESIGN

Sl.No.	Part Name	Count	Material
1	Frame	2	Steel
2	Fasteners	4	Steel
3	seat	1	Steel
4	Attachment	1	Steel
5	Back rest	1	steel
	Total	**9**	

The sustainability analysis was performed using sustainability section of SOLID WORKS package. The existing folding chair CAD model, materials, production processes were given as input. The output is the environmental impact. The existing design is made up of 36 components and made of steel and plastic materials. After the modification, the number of parts were reduced to 9 (Table 6). The environmental impact of existing and modified design as obtained from SOLID WORKS software is shown in Fig. 15 and 16 respectively. It may be observed that the environmental impact of modified design is reduced relative to the existing design. Table 7 gives a comparison of environmental impact of the chair designs. It shows that, all the parameters of environmental impact were reduced by little over 50%. This study indicates that the DFMA approach along with sustainability study helps in developing an economical and environmentally friendly design. This makes the design more sustainable.

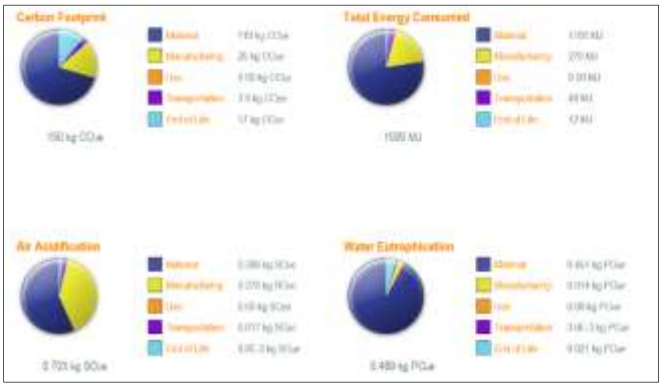

Fig. 15 Sustainability analysis of existing chair design

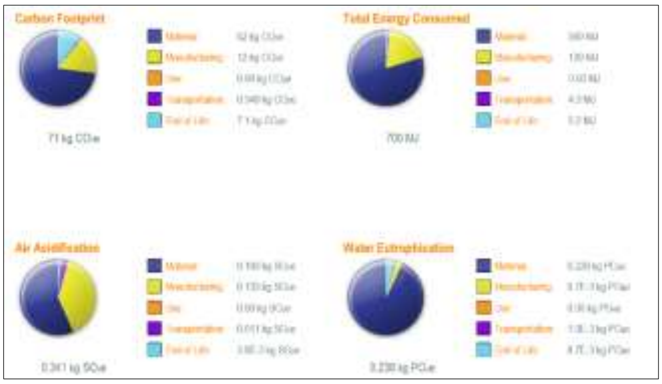

Fig. 16 Sustainability analysis of modified chair design

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TABLE 7: COMPARISON OF ENVIRONMENTAL IMPACT

Parameters	**Existing design**	**Modified design**	**% Reduction of environmental impact**
Carbon Footprint, kg CO_2	150	71	52.66
Air Acidification, kg SO_2	0.703	0.314	55.33
Water Eutrophication, kg PO_4	0.489	0.236	51.73
Total energy consumed, MJ	1500	700	53.33

4. CONCLUSIONS

From the above case studies, it implies that, DFMA is a reliable approach in analysing the design. The systematic approach of DFMA lead to the simple and less expensive products. The reduction in the number of parts through the use of DFMA results in snowball effect of cost and time minimization of the product. This in turn benefits the industries in achieving huge profits. By implementing DFMA right from the early design phase eliminated a lot of rework. DFMA allows the company to produce more effective products in less amount of time with a high quality. In addition, by implementing sustainability analysis, the companies can be more competent and relevant in the contemporary market. Sustainability analysis enable the designer in developing an eco-friendly product.

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