International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Design for manufacturing and Assembly practices in early stage of product development

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Received 20 Aug 2021, Accepted 24 Sept 2021, Available online 05 Oct 2021, **Vol.11, No.5 (Sept/Oct 2021)**

Abstract

This paper gives an overview of research that is expanding the domain of design for manufacturing (DFM) into new and important areas. DFM and assembly is widely used in industry, especially in product design and development process. to meet customer needs, companies are struggling with competitive markets to produce low cost products with high quality and faster to market. It becomes an important concept as the best time to find cost reductions, at design stage, rather than during manufacturing. The paper concludes with some general guidelines that suggest how manufacturing firms can develop useful, effective DFM. Overall goal with the paper is to aid designers, manufacturers, process planners in the practical industries on the ground and researchers in the mentioned area of study.

Keywords: *Design for manufacturing, Assembly, Product Design, Techniques.*

1. Introduction

In a context of deep change of industrial market related to globalization and delocalization, being competitive becomes a challenge for all industries. Developing successful new products requires the ability to predict, early in the product development process, the life cycle impact of design decisions. Downstream life cycle issues include considerations of how the product will be made, shipped, installed, used, serviced, and retired or recycled. Ignoring downstream issues (or producing poor estimates) leads to poor product designs that may cause unforeseen problems and excessive costs downstream. Sometimes, when problems are uncovered during design verification or testing, the problems can be corrected by redesign, but the cost of redesign at this late stage can be prohibitive. Sometimes companies must simply accept higher manufacturing costs and reduced product effectiveness resulting from early design errors.

If accurate predictions of life cycle needs can be made early in the design cycle, it allows product development teams to create superior designs. This not only reduces the number of redesign iterations, the time-to-market, and the development and manufacturing costs but also improves the customer's experience.

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DOI: https://doi.org/10.14741/ijcet/v.11.5.3

Unfortunately, downstream life cycle needs are difficult to predict accurately during early design phases for many reasons. (Swift KG, Brown NJ, 2003)

- The product specifications, dimensions and material of the product are not yet finalized, the manufacturing process and possible risks are very unpredictable.
- Number the life cycle issues and complexity of each cycle that must be considered are crushing.
- Other side the details of manufacturing, packaging and servicing may be outside the area of expertise of the designer.
- The knowledge compartmentalization problem is further exacerbated by the current trend towards locating manufacturing and service organizations overseas. Reducing energy consumption.

All the above factors contribute to insufficient consideration of product life cycle mainly manufacturing issues at design time.

To help designers better assess the downstream life cycle impacts of their design adoptions, manufacturer and researcher have developed many design choice support tools referred to as Design for X (DFX). The 'X' in DFX represents any one of a variety of design considerations occurring throughout the product life cycle, such as quality, manufacturing, production, or environment. A DFX can take many forms, it could be procedure or a set of guidelines on paper, or it could be a computer program that performs various types of

analyses resulting in cost, manufacturability, or performance estimates, which are then used by the designer in making decisions. DFX (design for X) methods provide approaches that consider a maximum of product life cycle information during the design process. A design solution is then the result of multiple expert product assessments and a collaborative multidisciplinary decision-making process. Design for Manufacturing (DFM) and Design for Assembly (DFA) are two of the most common and popular DFX tools.
Traditionally, DFA methods evaluate the ease of assembly, and DFM methods evaluate the feasibility and cost of manufacturing the product at the operation level. Recent product life cycle includes incorporation of DFM techniques at a variety of places in the product development process, including conceptual design, prototype design, detail design, and design verification. The most important result of the paper is a DFM and different design methods. To understand, How DFM techniques address a wide range of manufacturing and life cycle concerns including product quality, manufacturing system performance, life cycle cost, and environmental issues.

2. Literature Review

2.1 Product Life cycle:

A product life cycle is the amount of time a product goes from being introduced into the market until it's taken off the shelves. There are four stages in a product's life cycle—introduction, growth, maturity, and decline. Fig. 1 shows the product life cycle.

Fig.1 Product life cycle

2.2 Concurrent engineering

It is also known as simultaneous engineering, is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively. It decreases product development time and the time to market, leading to improved productivity and reduced costs. The main proposal of concurrent engineering is to shorten a product development time through a simultaneous time implementation of the several stages of the engineering activity in parallel and under a concurrent mode offering all information required by all elements of the product life cycle. Studies show that the design approaches affect the final cost of a new product more than any other factor. Fig. 2 CE design phases.

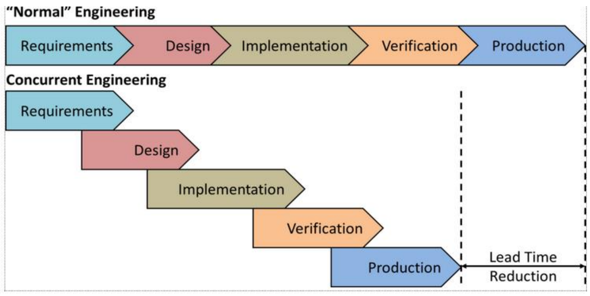

Fig.2 Concurrent Engineering

Design for manufacture (DFM): It is a product design approach that considers design goals and manufacturing information as soon as possible in product definition. Many studies deal with presentation and implementation of DFM concepts:
– Presentation of DFM concepts and tools (Poli C, 2001)
– Analysis of manufacturability and providing solutions to improve design (Lovatt AM, Shercliff HR, 1998 and 0Boothroyd G, Dewhurst P, Knight W,2001)
– Manufacturing processes selection based on processes classification and attributes comparison. Specification of appropriate method and techniques of materials and processes selection (Swift KG, Booker JD, 2003)
– Specification of techniques that will reduce cost and ease handling of components (Michele Modena,2019)
– Providing some fundamental rules of design that give the "best" solutions for manufacturing point of view (Pahl G. et al. 2007)

Five principles are examined during a DFM. They are:

- Process
- Design
- Material
- Environment
- Compliance/Testing

In summary, the scientific community proposes many studies of product manufacturability analysis based on different parameters (tasks, attributes, characteristics, cost, etc.) but it does not propose a synthesis (integration) method. Current approaches require pre-definition of product geometry and take place late in the detailed design stage, cycle cost, and environmental issues.

3. DFMA and different stages of concurrent engineering

3.1 DFM and Concurrent Engineering:

Generally, concurrent engineering (and DFM) is accomplished through a iterative "spiral" design process (shown in Fig. 3) in which marketing experts, designers, manufacturing engineers, and other personnel jump back and forth between identification of customer needs, design of the product, and assessment of manufacturing issues.

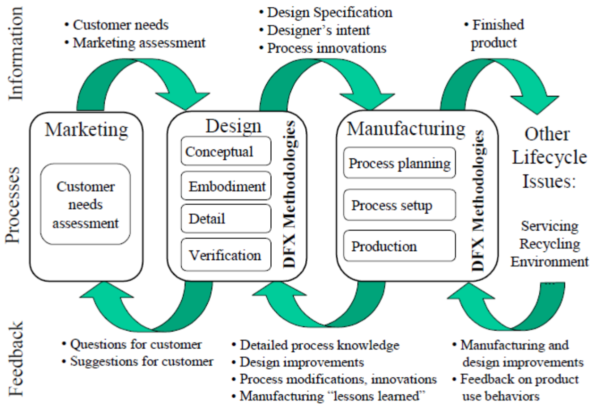

Fig.3 The Design for X Cycle

Barriers to effective DFM and concurrent engineering occur when the people performing marketing, design, and manufacturing cannot communicate or share knowledge. The reason could be

- Designers lack detailed knowledge of the current manufacturing practices and the
- Manufacturing engineers are not available to provide this assessment,
- Designers may not be able to do sufficient manufacturing assessments of their designs.

Due which the designer will only consider customer, internal legal and environment requirement while designing the part and no manufacturing requirements or barriers. The result may be assurance to a design that is unnecessarily expensive to manufacture. Before the industrial revolution, the salesperson, designer, and craftsperson were often the same person. This person had a detailed understanding of the customer's needs: how the design would meet those needs, and how it would be made. Concurrent engineering naturally occurred within that person's head.

3.2 DFM in embodiment design:

Embodiment design is well known in product development. Kesselring (1654) was the first to refer to embodiment design and introduced the guidelines: manufacturing costs should be less, optimum requirements, weights should be low, minimum losses and optimal handling. (MS Hundal. 1997). According to Pahl and Beitz, embodiment design can be described (1996) as: "it is treated as design process starting from very initial or concept phase of product. The design should be developed in compliance with engineering and economic criteria." (Dieter, G.E., 1991). It is a process where the structural development of the design concepts takes place. And in this phase that decisions are made on strength, material selection, size shape and spatial compatibility besides, where the design concept is invested with physical form. Embodiment design is concerned with three major tasks - product architecture, configuration design, and parametric design

3.3 Product Architecture

Focus of conceptual design is to find out the appropriate product architecture which can satisfy the product concept. To define the product architecture, one must identify the product elements and their assembly or linking between these elements. (F.Z. Krumenauer, C.T. Matayoshi, I.B. da Silva, M.S. Filho, G.F. Batalha, 2008). Generally, there are two types of product architecture, modular and integral. Modular architecture focus on linkage/connection/interaction between two modules/functions while integral architecture focus on each module/function its purpose and inner working.

3.4 Configuration Design

In this method designer develop a product or its element with the help of predefined components/functions and interaction between them. Configuration design is faster and cost-effective way of designing. In this phase designer provides the definition or dimension or shape to each component/function. (F.Z. Krumenauer, C.T. Matayoshi, I.B. da Silva, M.S. Filho, G.F. Batalha, 2008)

3.5 Parametric Design

In parametric design the attributes of components identified in configuration design become the look variables for parametric design. Determining the precise values, dimensions, or tolerances of the components orcomponent features that are deemed critical to quality. (F.Z. Krumenauer, C.T. Matayoshi, I.B. da Silva, M.S. Filho, G.F. Batalha, 2008)

Since it's at these stages that decisions regarding materials and shapes are made, this can be the planning stage which has the best influence on the materials flow cycle, production processes that are used, furthermore as many of the small print. Design of the merchandise in a very modular form allows for straightforward disassembly. The arrangement of the general layout can make it easier to perform the required steps in remanufacturing. The principle of division of tasks (function separation) utilized in embodiment design (TIMÁR, Imre, Tibor BORBÉLY, István LISZTES, and Pál HORVÁTH.,2010) should concentrate go down parts which might be easily conditioned.

The final design phase will finish the event of the products. At the top it's to be completely defined. For this process, the engineer has helpful principles, guidelines and also the three basic rules: simple, unambiguous, reliable.

- Unambiguous: -The use of product has got to be clear and uncomplicated (fulfillment of technical function)
- Simple: - There aren't any unnecessary functions or shapes apart from fulfilling the most function (economic realization)
- Reliable: - the merchandise is usable in an exceedingly myriad of conditions without harming the user or environment (safety for both humans and environment)

Current systems use simplistic approximations of production tool interval and production rate, which rely on the manufacturing facility. the subsequent generation of systems will must incorporate these parameters during a better way. Furthermore, current systems use only manufacturing costs in performing process and material selection. Because life cycle costs have a serious role within the decision, they must be considered within the next generation of systems.

3.4 DFM in detail design

Given the selection of materials and processes during embodiment design and facing the impending release of the product design to manufacturing, a host of DFM techniques are frequently applied in an effort to identify issues, catch mistakes, and avoid downstream changes. During detailed design, integration with Computer Aided Design (CAD) tools becomes critical to product and process analysis. For example, integration of Failure Modes and Effects Analysis (FMEA) and Computer Aided Manufacturing (CAM) into CAD is common.

Detail design is concerned with both the shape and tolerance of a part. Applying DFM to shape is highly process-dependent and can be accomplished through design standards or expert systems. More generic to all processes is the consideration of tolerance and its effect on function.

Specifically, FMEA is a DFM method used during detailed design that became so prevalent that it is now a military specification, MIL-STD-1629. In FMEA, the development team systematically evaluates and documents each failure mode, as well as the failure mode's potential impact on system performance, safety, and maintenance. Each failure mode is then ranked by the severity of its effect in order that appropriate corrective actions may be taken to eliminate or control the high-risk items. Subsequently, further detailed, embodiment, or even concept design may be required to address the revealed shortcomings. Current research (Chao and Ishii, 2003) is striving to lower the burden of conducting FMEA through automation with wizards while extending and validating its usefulness. FMEA can address manufacturing operations to identify ways in which the product design leads to manufacturing problems.

The analysis of tolerances and tolerance stack-up remains important. Previously, industry standards were blindly accepted as limits on product design and manufacturing. Currently, Six Sigma approaches promote the characterization and classification of manufacturing processes, with downstream statistical data being fed back to set the component tolerances during detailed design. Simultaneously, engineers have begun using analysis techniques such as Monte Carlo analysis to predict the distribution of the design performance, rather than simply accepting or rejecting the design based on worst case scenarios. Using these techniques, engineers can correctly recognize, specify, and control those few tolerances that dominate the design performance,thereby leading to improved product performance at lower cost.

In addition to FMEA, CAD/CAM software is an important DFM tool for detailed design that utilizes CAD software to describe part geometries to, for example, define toolpaths to direct the motion of a machine tool to form the part. Today, most new machine tools incorporate CAM and Numerically Controlled (NC) technologies. To further facilitate DFM, CAD/CAM systems can be integrated with process planning and other technologies such as Group Technology (GT) and Cellular Manufacturing. Finally, Flexible Manufacturing Systems (FMS) and Just-In-Time Production (JIT) are important concepts made possible by CAD/CAM systems, affecting the integration of manufacturing cells, productivity and quality in a wide variety of strategic industries (e.g., http://www.gsd.harvard.edu/inside/computer_resources/manual/cadcam/whatis.htm).

No matter the stage in the design process, DFM is recognized as an important component of product development. As such, practice and theory have developed within very specific areas of DFM including Design for Quality, Design for Production, Design for Life Cycle Cost, and Design for Environment, as described below.

3.5 DFA in detail design

DFA (Design for Assembly) is a DFM specialty; it is a structured method to improve product components assembling. Both, DFM and DFA are essentials applications during product design and are also called DFMA (Design for Manufacturing and Assembly). The following criteria are considered in a DFA study:

- Reduce and optimize part counts and types.
- Utilize optimum attachment methods.
- Use layered assembly approach. Let gravity help.
- Minimize reorientations during assembly.
- Eliminate the need for adjustments.
- Design parts so that they are easy to self-align and locate.
- Ensure adequate access and unrestricted vision.
- Ensure ease and safety of part and assembly handling.
- Design parts that can only be installed correctly.
- Minimize the number of tools required.

3.6 Future of DFMA Software

Considerable research and development in the area of product design for manufacture and DFMA has been carried out in the past 25 years. The underlying philosophy of this work is the early design decisions on product configurations, together with the selections of materials and processes, lock in a large proportion of the subsequent manufacturing costs. The DFMA software is a combination of two complementary tools, DFM and DFA. The DFM cost program uses an extensive materials database that includes the materials related parameter for each process. This database also includes processing limits data that aid material and process selection by indicating combination suitability for a given part (Olga Battaïa, Alexandre Dolgui, 2019)

The DFMA software offers a huge savings in time and money. It will assist in the decision-making process for a product design. Another interesting point, the user can generate several design options to do some comparison. This software also has one of the most extensive libraries for product's materials, production processes, fasteners and additional production operations.

John Deere Selects DFMA Software from Boothroyd Dewhurst, this could enable Deere to reduce the cost of purchased parts in the company's major equipment divisions. John Deere is the world's premiere producer of agricultural equipment and the world leader in forestry equipment, as well as major supplier of construction and lawn and turf care equipment. DFMA software is a combination of two complementary tools: Design for Assembly (DFA) and Design for Manufacture (DFM). Engineers use DFA software to reduce the assembly cost of a product by consolidating parts into elegant and multifunctional designs. DFM software then allows the design engineer to quickly judge the cost of producing the new design and to compare it with the cost of producing the original assembly. An extensive library in the software enables product developers to investigate alternative materials and processes for producing parts and helps them select the most cost-efficient design. The cost management group at John Deere works with cross-disciplinary teams that include members of the supply chain. The teams review a bill of materials for a part to establish a benchmark. They then perform DFM analyses of materials and manufacturing processes to re-design the part and provide the supplier with a should-cost estimate based on the new design.

4. DFMA and different stages of concurrent engineering

General guidelines for successful implementation of DFMA varies per organization, industry and product. However, the followings are guidelines generally provided to cost optimization (F.Z. Krumenauer, C.T. Matayoshi, I.B. da Silva, M.S. Filho, G.F. Batalha, 2008.)

- Minimize the number of (different) parts in a product,
- Use standard available components,
- Design parts that can be used in multiple product lines,
- Design components that are simple to produce,
- Minimize the number of flexible components,
- Design components that are multifunctional in a product,
- Design parts that cannot be assembled incorrectly,
- Maximize symmetry of parts or design them deliberately asymmetrical,
- Ensure that parts align themselves for assembly,
- Design products that fit in standard packaging,
- Design the product modular.

5. **Case Studies**

Below selective case studies show the actual issues identified in an agricultural equipment manufacturing company.

DFMA was done on new product in very early phase and all modules were analyzed in detail using DFMA guidelines. The critical cases were shared with product engineers and solutions were developed and implemented in design before the actual build of the product.

This exercise helped to avoid the rework which could have occurred during actual assembly and in terms reduce the project milestone timeline.

4.1 Case Study 1: Design for Ergonomic assembly

In below (Fig 4) situation the part is being held by one hand and placing in a fastener with the other hand.
Weight of the part is more than 8 kg and the assembly lone runs with high volume per shift.

Parts under 10 Kg could still pose an ergonomic concern when they must be manually positioned and held in place to install. This can become an ergo issue over time.

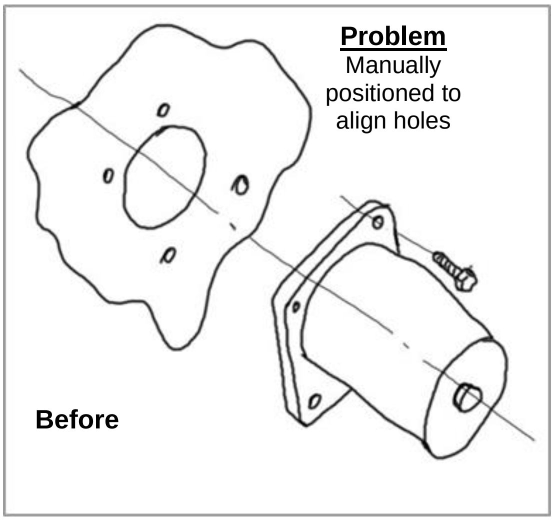

Fig. 4 Product design before DFMA

Solution after DFMA:In (Fig.5) Adding a simple lip to support the weight of the part and align holes for assembly resolves issue.

The extra lip provided hold the part and bear the weight, so operator now can easily assemble the hardware without much efforts for lifting the part.

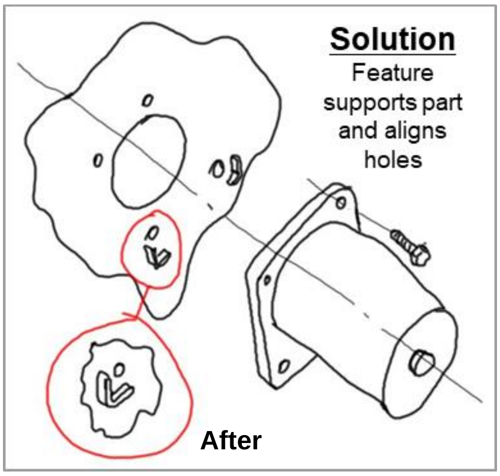

Fig. 5 Product design after DFMA

4.2 Case Study 2: Design for Tool & Operator Accessibility

In (Fig 6), part is assembled on the C channel using spacer along with bolt and nut. And then nut is tightened with wrench.

In this assembly, operator has very limited space to assemble the nut and don't have much visibility. Also, Wrench don't get the required 60 degree of span to tighten the nut due to restricted access

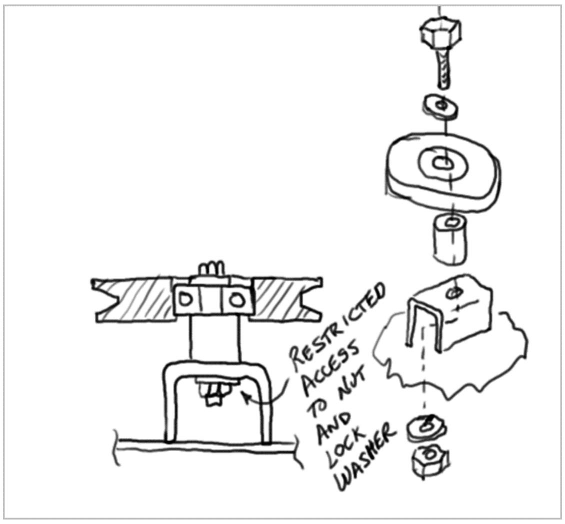

Fig. 6 Product design before DFMA

Solution after DFMA: In (Fig.7) Design is changed and assembly will be done from top to down. In this case part count is also reduced and Operator has no restriction for assembly and tightening the nut with wrench and has got clear visibility.

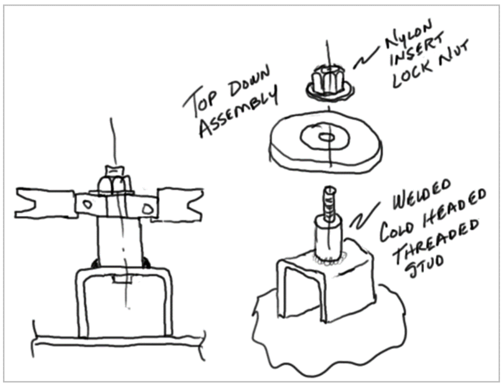

Fig. 7 Product design after DFMA

4.3 Case study 3 - Design to Largest Functional Tolerance Compatible w/Factory Capability

In (Fig.8) A two bolt bracket is secured to another part. Parts must bolt together at extreme limits of tolerance.

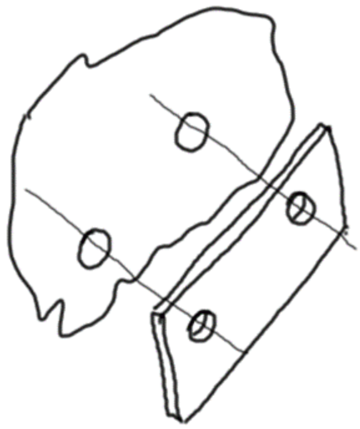

Fig. 8 Product design before DFMA

Solution after DFMA:(In Fig 9) Hole alignment can be assured using tight tolerances and geometric positioning, but may dictate a more expensive process, such as drilling. Designing the part with a hole and a slot allows part to be held in same position as 2-hole design, but made with a less expensive process, such as stamping.

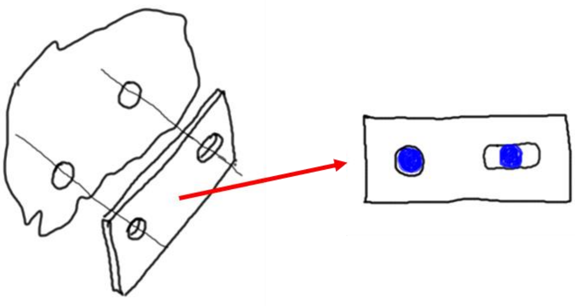

Fig. 9 Product design after DFMA

4.5 Case Study 4: Design for Parts Orientation and Handling

In (Fig.10) – before here Hole alignment is major problem. The part is bolted to frame after placing it on the frame.

Part weight make holes difficult to align and cannot be assembled in target cycle time

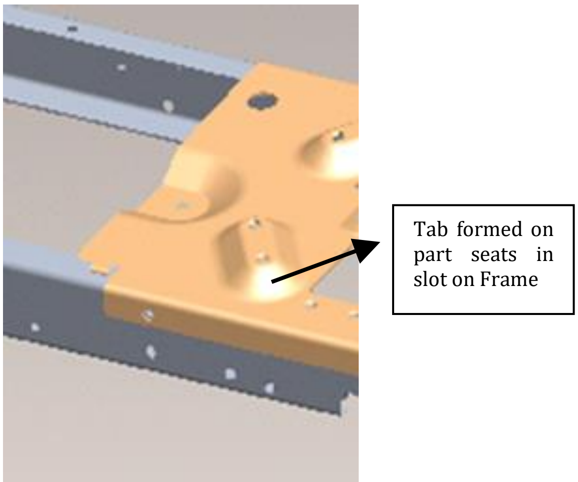

Fig. 10. Product design before DFMA

In (Fig. 11) – Self aligning feature is added in the design. Locating" tab added to part from existing material

Tab assembles in slot in frame and aligns all mounting bolt holes

Part can easily be assembled under target cycle time

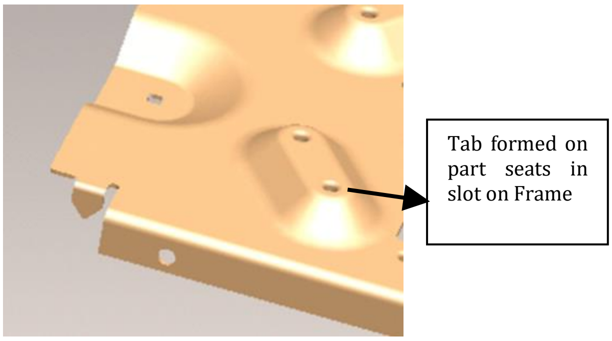

Fig. 11 Product design after DFMA

Conclusions

This Research paper presents the scope of DFM tools which has expanded in many ways: to applications for different phases of design, to manufacturing system performance, to platform design and system quality, and to life cycle cost and environmental considerations. Though this variety is tremendous, there are some general guidelines that suggest how manufacturing firms can gain from DFM tools.

DFMA is a good method to optimize a design for mass production at an early stage, so that the product can be efficiently and effectively be produced and assembled. Also, for an existing product it may be worth to carry out a DFMA study to reduce costs and improve quality. DFMA tools are useful in reducing the time taken to evaluate designs and therefore it should be implemented as part of the design selection process.

With the help of case studies, it is revealed that how DFMA beneficial for identifying the issues in product design and product manufacturing if we apply it in early stage of product development and also it can enhance ergonomic conditions of operator and reduce product launch time.

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