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DFMA+, A Quantitative DFMA Methodology

Ramy F. Harik[1] and Najwa Sahmrani[2]

[1]Lebanese American University, ramy.harik@lau.edu.lb
[2]Lebanese American University, najwa.sahmarani@lau.edu.lb

ABSTRACT

Developed DFMA methodologies are qualitative based and often described with general guidelines. Such methods require experienced designers, assemblers and manufacturers with profound knowledge in order to evaluate the ability to assemble and or manufacture a certain product. In this paper we are presenting a detailed review state of the art of DFMA methodologies. Following this study we will identify the main parameters to be investigated in a DFMA study. For each parameter a weight will be assigned and a quantitative methodology (Value Engineering) will be identified,based on the part's morphology, the process and the available resources. These methodologies will be described and applied on two study cases. A tool DFMA+, currently being developed, will be exposed. The article will end with conclusions on the present work and perspectives to enhance the current methodology.

Keywords:DFMA, CAD/CAM, knowledge management, value engineering.
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1 INTRODUCTION

Design for manufacturing and assembly – DFMA – concepts has proven to give us the ability to estimate assembly and part manufacturing costs at the earliest stages of product design. Not only cost and time are reduced but the sequence of manufacturing processes is more efficient, in addition to the significantly improved quality of the product. As DFM has been playing a vital role for the industries that applied it, working on broadening its application would be very beneficial economically and environmentally. DFMA technologies should be based on the concept of: Eliminate whenever possible then re-order to optimize. [13] compared several DFMA methodologies and concluded that some methodologies reduced time up to 70%.
In section 2 of this paper a state of the art of the current DFMA methodologies is exposed. Theadvantages and deficiencies of these methodologies are highlighted. In section 3, a study of the several parameters essential to conduct a DFMA study is identified. The list is compiled and formulated in a table constituting a quantitative approach based on value engineering.Then in section 4 three case studies will follow to simulate the application of this approach.This computation should classify the manufacturability and assembly ability for a specified part using a preset resources list. This tool is still in its architecture identification stage awaiting the ability to apply it in an industrial context. The article ends by presenting the status-quo of the methodology proposed and stating the perspectives of developing and enhancing this method.

2 STATE OF THE ART

Extensive research has been conducted to explore DFM and DFA Methods.These methods fall under two categories: creative thinking that rely on the intuition of the designer(Qualitativeapproach) and, logical methods (Quantitative approach) which encourage a systematic approach to design[9].
For a conventional CAD system an analysis of manufacturability is a preliminary activity for successful integration of manufacturing in design.The transition process to move from a specified geometry to a final product is sequential and iterative. It is done by iterations between designers andmanufacturing engineers.By implementing the Concurrent Engineering approach, the industrial world seeks to integrate the work of CAM in the activity of CAD to satisfy the requirements that are manufacturing in a short time period at low cost withgood reliability[13].In fact, when designers lack detailed knowledge of the current manufacturing practices and the manufacturing engineers are not available to provide this assessment, the designers may not be able to perform sufficient manufacturing assessments of their designs. The result may be a design that is unnecessarily expensive to manufacture [8].Basically, Concurrent Engineering is the practice of simultaneously developing solutions that address multiple life cycle issues. Engineered systems are usually too complex to truly consider all issues simultaneously. Thus concurrent engineering (and DFM) is accomplished through an iterative "spiral" design process[8].It's important to implement it though all phases of design, conceptual design, and embodimentdesigndetailed design and then the final enhanced design.DFM is an analysis of the product to make its definition compatible with the definition of its manufacturing process. The DFM methodology generally is assimilated to assess the feasibilityindustrialization of the product [2].The analysis of manufacturability of a design proposes means of determining whether the design is manufacturable or not [5].

The main guidelines of DFM systems, specified by[1], are in general:

- Reducing the number of parts in the assembly:The more there are components in an assembly the more there is possibility to make mistakes during constraint settings. The opportunity of obtaining a "good" product decreases exponentially over the number of its parts.
- Use of standard and common work (billet) material: The use of traditional material (i.e. titanium or aluminum) will facilitate the task of the study.
- Elimination of cables and adjustments: Reducing the number of cablesreduces assembly time and therefore cost. Similarly, elimination of adjustment decreasesconsiderably the complexity of the assembly.
- Use of available machining resources: By studying how well existing production withinthe company sought to eliminate non-functional complex entities difficult achievable in the context of production.

DFM methods are various but they all share the same concepts, they must fulfill at least one of these tasks: present a non-patterned approach to problem solving, keeping in view manufacturability, yielding desirable solutions, Specify rules and techniques that will improve assembly techniques at reduced cost, ease handling of components, specify rules and techniques for economic manufacture, appropriate selection of materials and processes, help in achieving a final robust design, improve a product's quality[9].Among several methods we mention those most commonly cited:

- Grabowick's Methods [4]: Their principle is based on two methods: The first is to identify for a given product, a similar existing product. The corresponding machining processes can then determine the specifications.The second method is based upon the identification of construction features and technological entities.
- The Lucas DFM methodology[14]: This method integrates various modules like Quality Function Deployment, DFA, manufacturing analysis, design to cost, etc.
- CyberCut[15]: This method uses a feature based design system in parallel with a knowledge based process planner. The design process used is DSG (Destructive Solid Geometry).
- The Nippondenso Method and DFM Guidelines[11]: Nippondenso is a car products company in Japan. The company came up with a method that consists of dividing the product into generic

parts or sub-assemblies and designing the parts for interchangeability, so a variety of products may be produced.

- Producibility Measurement Tool[16]: This manufacturability evaluation method relies on opinions of experts based on their past experience. A producibility index is computed using a Producibility Assessment Worksheet (PAW). An important aspect of this tool is the review of the preliminary drawing or sketch of the product by a manufacturing engineer along with design engineers.
- Feature Based Manufacturability Evaluation[17]: Gupta and Nau have presented an approach for the manufacturability analysis of machined parts.The method consists of generating all the possible machining features for the designed part assuming all information on tolerances and surface finish are available, and then group them into a feature based model (FBM) to remove redundant machining operations and build an enhanced FBM.
- A Framework for Manufacturability Evaluation[10]: This is also a feature based manufacturability evaluation method developed by Shah et al. The system developed allows interactive creation of geometric models. The designer may submit the feature to be evaluated whether or not the design is complete. The system goes on to determine an optimal sequence of processes based on cost.
- Zhou's Methodology[12]: his work led to anessential tool based on feature recognition to generate proposals to re-design. It can transform a design containing non-machineable shapes into a manufacturable design. Their approach is developed in a software product (ARM, Automated redesign for machined part) re-design for machined parts. The software uses information from the forms of identification that cannot be machined with the available equipment. By studying patterns of machining (side, end) the system determines if the faces are machineable or not.With this system the user has an option of automatic re-design by adding design elements.

To evaluate manufacturability and efficiency of any DFM method seven factors, as defined by [3], must be reviewed:

- Cost of production, it must be minimal costs including direct and indirect
- Quality and compliance with specifications,
- Flexibility to adapt to changes in production,
- The ability to limit risk
- A short period of manufacture,
- Efficiency in the use of resources and human capital of the company,
- Minimizing environmental impacts.

To wrap up, it is evident that the current DFMA methodologies need to be improved. They provide the required guidelines for assessment of the manufacturing process and they give insight for proposing an alternative for re-design butthe quantitative approach must be accentuated and developed for DFMA methodologies to be truly efficient. Time and cost factors would be drastically reduced by such methodologies.

3 METHODOLOGY

In the following paragraph, we will conduct an extensive analysis for the previously exposed methods. This analysis will identify the main parameters to investigate in any DFMA application. Furthermore, an examination of these parameters will facilitate the assignment of a weight for each individual factor. Eventually, these elements will be regrouped in a value engineering table.

3.1 Parameters Identification

The table belowprovides all the parameters of DFM and DFA analysis. Some elements are common and some are exclusive.

DFM/DFA Parameters	Manufacturing	Assembly
Billet Dimensions	Machine Selection Availability of standard Billet	Manual or Automated
Work Material Properties	Ease of manufacturing	Physical Properties – Density, volumetric cost.
Features	Machining Time based on type	Tangling Jam Slippery
Thin Features	Particular Manufacturing	Special Handling
Tool Identification	Availability in workshop	-
Manufacturing Fixtures		
Machine Accessibility		
Operations Sequence	Grouping similar operations Eliminating redundancy	-
Part Handling	-	Sharpness Slippery Flexibility
Assembly Fixtures	-	Availability Selection of the mostsuitable
Standard fastening parts	-	Availability Cost
Chamfer to guide insertion	-	Availability
Number of Parts		Assembly time
Tolerance and clearance	-	Insertion Time and Effort

Tab. 1:Analysis of the influence of the different DFM/DFA parameters.

3.2 Weight Study

In this section, two separate weight studies of DFM and DFA parameters will be conducted, each one represented in a table. The tables will define the different important factors and will cite the set of parameters derived from them. Features type is the core of the DFM weight study where as for DFA the number of parts and additional parameters are very important too.

3.2.1 DFM

Name	Definition	Parameters
Billet	*Standard*: Billets are available in standard shapes and dimensions. A part whose billet is standard will induce a lesser cost. This fact is supported by the availability of the billet in the workshop inventory. *Dimensions*: The size of the billet is very essential for the machine selection thus it is constrained by the machine availability.	*m_billet_standard* *m_billet_dimensions*
Work Material	*Cost*: The material volumetric cost is not the only factor. *Availability*: Availability counts as well. *Properties*: In addition, the physical properties of the material, such as tensile strength and rigidity, affect the ease of manufacturing. Depending on the required specification, the operator selection of the material might not be justified in terms of manufacturing perspective.	*m_material_cost* *m_material_availability* *m_material_properties*

Features	In the early stages of design, it is important to notice that some features' manufacturing is more costly, i.e.: a square hole is much more expensive than a circular one. Recognizing the type of each feature determines the identification of the machine and the tool and the corresponding fixture. Features that are non functional can be considered as undesirable with respect to cost reduction. A good software solution should indicate these features and propose to the operator to eliminate them. If the operator decides to keep them, it will inform him of the additional cost set by the presence of the mentioned feature. *Feature Type*: Functional, Esthetic	*m_feature_function* *m_feature_type*
Thin Features	In some cases, the designer is constrained by weight properties (i.e. designing parts for aircrafts, or designing automotive parts with fuel consumption constraints). The desire to reduce the part weight generates the existence of thin features that requires a special manufacturing methodology.	*m_thinfeatures*
Tool Identification	The identification of the tool required to obtain a certain manufacturing feature is essential. In fact, if the tool is not available in the workshop the industry will have to order special tools to realize the manufacturing feature in study. This function should inform the analyst that the element he is designing (or studying) will require non available tools.	*m_tool_availabilty*
Manufacturing Fixtures		*m_fixture*
Machine Accessibility		*m_machine_availability*

Tab. 2: Identification and Definition of DFM parameters.

3.2.2 DFA

Name	**Definition**	**Parameters**
Billet Dimensions	*Dimensions*: The size of the billet is one of the important parameters that predefine whether the assembly must be automated or manual.	*a_billet_dimensions*
Work Material	*Properties*: The physical properties of the material, such as volumetric density and rigidity, affect the handling time and whether the part requires special handling. Thus it affects the assembly cost.	*a_material_properties*
Features	During the design of complementary parts, the designer must provide features that does not easily tangle and that prevent jamming.	*a_features_type*
Thin Features	Thin features require special handling thus increases the handling time and effort.	*a_thinfeatures*
Part Handling	For ease of part handling, the designed parts should either be symmetrical or clearly asymmetrical. Slippery and flexible parts require special handling thus increases the handling time. In addition, Sharpness of the part causes safety problems in the case of the manual assembly	*a_part_symmetry* *a_part_slippery* *a_part_sharpness* *a_part_flexibilty*
Assembly Fixtures	When selecting the most suitable fixture for an assembly process, availability of the fixtures in the workshop is a very important factor to examine.	*a_assembly_fixtures*
Standard fastening parts	Using common parts and methods for all the product line, simplifies the fastening process. In addition, it	*a_fastener_standard*

	should be noted that using common mechanical fasteners with standard dimensions decreases the cost of assembly.	
Chamfer to guide insertion	If it is possible to chamfer a part to guide the insertion of two mating parts, the assembly would be much easier and less time consuming.	*a_chamfer*
Number of Parts	The first guideline for DFA is decreasing the number of parts in the designed product. It decreases drastically the cost and the assembly time.	*a_parts_number*
Tolerance and clearance	Insertion Time and the required effort for assembling two mating parts decreases relatively if enough clearance is maintained and the tolerance is high enough.	*a_tolerance* *a_clearance*

Tab. 3: Identification and Definition of DFA parameters.

3.3 Value Engineering

Parameter	**Weight**	**Value Assigned**	
m_billet_standard	10	Regular = 0	Irregular = 1
m_billet_dimensions	4	Intermediate or less = 0	Other = 1
m_material_cost	2	Low= 0	High= 1
m_material_availability	1	Available=0	Not available=1
m_material_properties	8	Easily manufactured= 0	Other=1
m_feature_function	3	Functional=0	Esthetic=1
m_feature_value	10	Up to 25 features with a maximum of 5 complex features= 0	Other = 1
m_thinfeatures	8	Not Available= 0	Available= 1
m_tool_availabilty	5	Available= 0	Not available= 1
m_fixture	6	Available= 0	Not available= 1
m_machine_availability	10	Available= 0	Not available= 1
a_billet_dimensions	10	Manual Handling= 0	Automated= 1
a_material_properties	2	Manual Handling= 0	Automated= 1
a_features_type	5	Easily inserted= 0	Other = 1
a_thinfeatures	4	Not Available= 0	Available= 1
a_part_symmetry	2	Available = 0	Not available= 1
a_part_slippery	5	Non Existent= 0	Existent= 1
a_part_sharpness	4	Non Existent= 0	Existent= 1
a_part_flexibilty	6	Non Existent= 0	Existent= 1
a_assembly_fixtures	1	Available= 0	Not available= 1
a_fastener_standard	5	Standard = 0	Non-standard= 1
a_chamfer	5	Existent= 0	Not Existent= 1
a_parts_number	10	Less than 10= 0	Other = 1
a_tolerance a_clearance	8	Not tight= 0	Tight= 1

Tab. 4: Parameters weight study.

In this paper, the assigned value is either 0 or 1 while a larger scale can be considered when further developing the methodology. The lower the total grade of the part and the assembly is, the more efficient it is. However it is undesirable to compare the grades of the parts and specify a firm range. Every company should define its own range and limits based on its resources and needs.

4 CASE STUDY

In this section, two different case studies will be presented for DFM and DFA analysis. The choice of the case studies is based on the complexity in design and assembly in order to highlight the different aspects of the parameters.

4.1 DFM Case study:

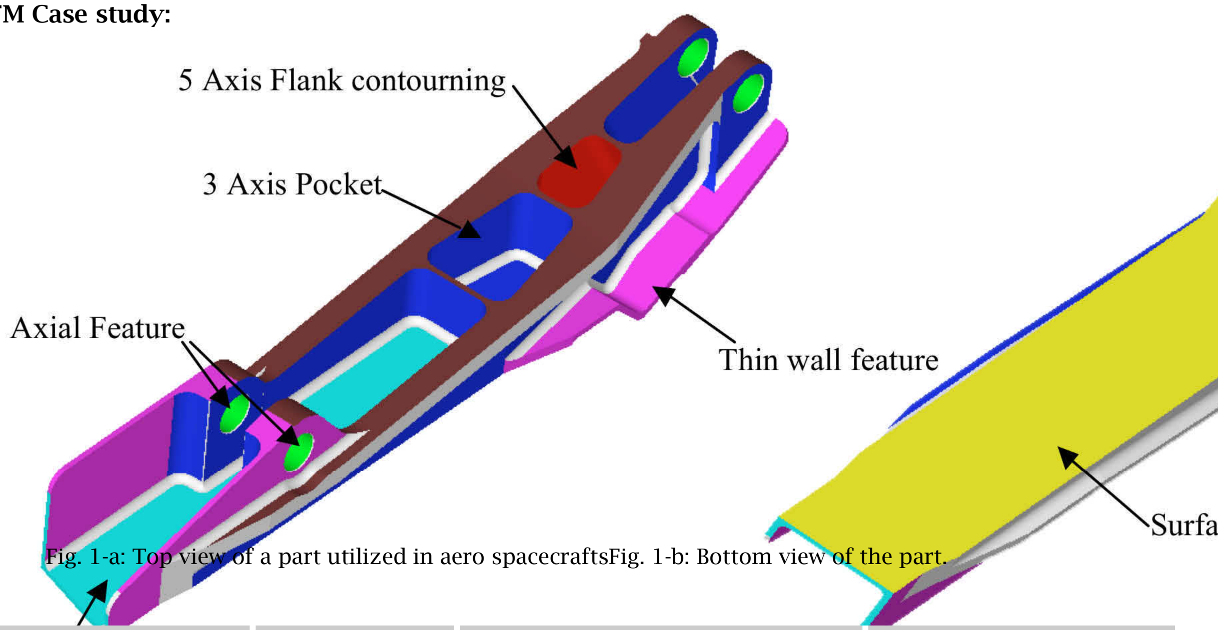

Fig. 1-a: Top view of a part utilized in aero spacecraftsFig. 1-b: Bottom view of the part.

Parameter	Weight	Description	Total
m_billet_standard	10	Irregular = 1	10
m_billet_dimensions	4	Other = 1	4
m_material_cost	2	Titanium, expensive = 1	2
m_material_availability	1	Not available = 1	1
m_material_properties	8	High tensile strength = 1	8
m_feature_function	3	Functional = 0	0
m_feature_value	10	Complex features = 1	10
m_thinfeatures	8	Available = 1	8
m_tool_availabilty	5	Not available in workshop = 1	5
m_fixture	6	Not available in workshop = 1	6
m_machine_availability	10	Available in workshop = 0	0

MAX:67TOTAL: 54

The total grade of this part is 54. Compared to the maximum grade 67, this part is considered costly and need some design improvements. To improve the part, the designed features should be less complex if possible and compatible with the machines available in the workshop.
But as mentioned before, we cannot specify a range for failing parts. It is a case by case study, depending on the needs and resources and the restrictions of the design.

4.2 DFA Case study:

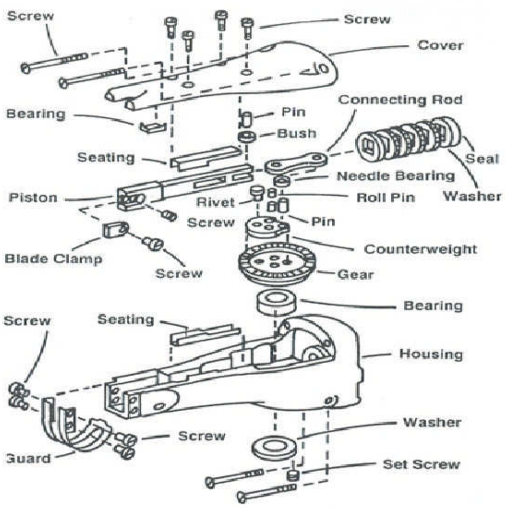

Fig. 2: Power Saw – 41 parts.

Parameter	Weight	Description	Total
a_billet_dimensions	10	Automated= 1	10
a_material_properties	2	Automated= 1	2
a_features_type	5	Not easily inserted= 1	5
a_thinfeatures	4	Available= 1	4
a_part_symmetry	2	Not Available = 1	2
a_part_slippery	5	Existent= 1	5
a_part_sharpness	4	Existent= 0	0
a_part_flexibilty	6	Non Existent= 0	0
a_assembly_fixtures	1	Available= 0	0
a_fastener_standard	5	Non Standard = 1	5
a_chamfer	5	Not Existent= 1	5
a_parts_number	10	41 parts = 1	10
a_tolerance	8	Tight= 1	8

MAX:67TOTAL:56

The total gradeof this assembly is 56. Compared to the maximum grade 67, this assembly is considered extremely time consuming and costly thus needs some drastic changes in the design phase. A proposed solution would be to reduce the number of parts. Furthermore, modifying certain features so that the mating parts would be symmetrical and not jam or tangle, in addition to the use of standard fasteners, would result in very high savings in assembly time.

5 CONCLUSIONS

Design for Manufacturing /Design for Assembly principles are at least 200 years old. Although they provide a huge potential savings, the current methods does not make a full integrated system. There is not a unique existing way of implementing these principles and methods, yet most of them are qualitative based. In this paper, a quantitative method was suggested, requiring proposed software to be applied. Once developed and improved, this method will make the implementation of DFMA simpler and more efficient.

6 PERSPECTIVES

The DFMA+ approach presented in this paper is currently being developed. Major improvements and in-depth studies should be carried. The grading of a part or an assembly based on the weight study will be taken to a higher level by exploring furthermore the different aspects of each parameter.
Each company or industry should be able to modify the software according to its own resources and requirements. This tool is expected to give a detailed DFMA analysis and identify the areas where the design must be improved.

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