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INTEGRATION OF DFMA THROUGHOUT AN ACADEMIC PRODUCT DESIGN AND DEVELOPMENT PROCESS SUPPORTED BY A PLM STRATEGY

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ABSTRACT

Quantitative Design for Manufacture and Assembly (DFMA) approaches are often applied during the last stages of the Product Design and Development Process (PDDP) as a unique activity, but it would be integrated more efficiently working from the first stages throughout the whole process according to the Concurrent Engineering philosophy. It is proposed a holistic PDDP where the activities and tools of DFMA Methodologies are integrated through its different stages in a single and distributed way, in order to obtain an integral implementation of DFMA in a “Product Lifecycle Management –PLM” strategy further along. This attempt is oriented to the implementation of a holistic PLM strategy in a standardized academic PDDP in the B.Eng. in Product Design Engineering at EAFIT University-Colombia. Besides, it is an initial proposal to integrate DFX methodologies in PLM, seeing that previous experiences have demonstrated that, at academic level, in projects where the application of all taught courses should be evident in the final designed products, students forget to apply considerations related to manufacturing and assembly issues.

Keywords: Design for Manufacture and Assembly, Concurrent Engineering, Product Life-cycle Management, Product Design and Development Process.

1 INTRODUCTION

Quantitative Design for Manufacture and Assembly (DFMA) Methodologies are often located in the Product Design and Development Processes (PDDP), proposed by authors like Baxter[1], Ullman[2] and Otto & Wood[3], in the last stages of the process as a single unit or activity. However, in practice, such integration could result belated and inefficient due to the high number of cycles, iterations and re-processes that this comes with. This situation is unfavorable to Concurrent Engineering philosophy that tends to take into account all the constrains and requirements related to manufacture and assembly procedures from the first stages of the design process in order to carry out it efficiently, minimize costs and ensure a quick time to market[4].

Most of integration between DFMA and Product Lifecycle Management (PLM) are based on systems and applications developed to support and automate a particular method or activity. However, although these applications facilitate more efficient activities, there are not approaches developed to assist the strategy formulation which is the most important stage in a PLM implementation.

In this way, it is proposed an initial approach that identifies and separates the activities and tools of well-known DFMA Methodologies, specifically Boothroyd & Dewhurst [5] and Lucas [6] methodologies, and integrates them to the PDDP in a distributed way, locating each activity or tool at an earlier stage, in order to reduce the number of design cycles and iterations. This attempt relies on an ongoing research project carried out by the Research Group in Product Design Engineering – GRID, at EAFIT University-Colombia, in order to define a holistic academic PDDP based on a PLM strategy and managed by the open-source PLM system so-called ARAS [7], to be implemented at the B.Eng. in Product Design Engineering during next academic projects. For the time being, this holistic PDDP is being implemented in academic projects and future results will be used for further modifications and tuning.

2 STATE OF THE ART

2.1 DFMA and PLM integration

It is becoming a common feature to find literature related to the incorporation of DFMA methodologies and tools within a framework of Concurrent Engineering that enables their efficient development. Edwards [8] works on the strategic implementation of materials and manufacturing process information through the design process, with emphasis on the DFMA integration in the process; Belay [4] analyzes the product development process of two companies from the DFM and concurrent engineering perspectives and proposes an implementation guide to evolve from a sequential process to a concurrent process; and Gomes *et. al* [9] make use of PLM systems to generate a DFA methodology for the semiautomatic development of assemble sequences based on information from CAD models and DFA guidelines.

This kind of methodologies is usually assisted by systems developed specifically to support the methods and activities that compose them. Howard *et. al* [10] propose the development of expert systems useful to analyze alternative manufacturing methods for a product design through a data base usage.

Here is where PLM plays an important role, because it enables and integrates this kind of methodologies and systems in order to manage, to automate and to facilitate their concurrent performance through collaborative engineering and knowledge management. So, Spiteri *et. al* [11] propose a mobile system of knowledge management that assist New Product Development (NPD) process, even when designers are away from their usual workplace; Huang *et. al* [12] present an application of DFMA techniques via Internet equivalent to existing versions of a standalone Workstation; Qiao *et. al* [13] create an information model for manufacturing process simulation based in XML; and Wang *et. al* [14] implement a "Design Decision Support System" DDSS to assist the decision making process related to manufacturing issues, taking as case study a DFM process.

Even though there are a large number of methodologies proposed for the DFMA deployment in the design process, aforementioned researches do not propose a methodology to separate activities and tools of a DFMA process and integrate them throughout the PDDP and they are mostly focused in the performance of specific activities which are managed by the PLM system rather than a holistic view that allows planning and strategy development.

2.2 PRODUCT DESIGN AND DEVELOPMENT PROCESS (PDDP)

PDDP is defined as a series of activities which are organized in a specific way in order to reach products that meets the requirements of a project [15]. Most of these processes are iterative in order to evaluate and test ideas, concepts or proposals as is the case of Pugh [16]. This iterative nature of the process creates a series of cycles and loops that along with divergent-convergent thinking methodology [17] contribute to product development that meets all the requirements and constraints established around it.

Usually this kind of process is composed by a series of phases that integrate the NPD such as requirement definition, conceptual design and detail design, however during last decades the previous process known as Fuzzy Front End (FFE) has gained importance in literature [18] so that some authors take into account, in their design process, phases like market [16], business opportunity [1] or activities like marketing [19] into planning or product planning phase [20].

Although these cycles are important for the feedback process, a huge number of iterations could imply a delay in time to market that is one of the most important items considered in fourth and fifth generation innovation process [21].This situation could be avoided through a more efficient location of activities like DFMA through the PDDP.

In order to achieve this, members of the Research Group in Product Design Engineering analyzed several design processes such as Pahl & Beitz[20], Ulrich & Eppinger [19], Ullman [2], Baxter [1] and Otto & Wood [3]; the academic PDDP adopted by the B.Eng. in Product Design Engineering at EAFIT University and the PDDP performed by different goods-producing industries in Medellín-Colombia.

3 PROPOSED HOLISTIC PDDP

As above mentioned, the integration of DFMA throughout a PLM strategy is based on the development of a holistic PDDP for the B.Eng. in Product Design Engineering. That process would allow inclusion of tasks, information and tools of DFMA methodologies of Boothroyd & Dewhurst [5] and Lucas[6], into the PDDP in a concurrent way, reducing unnecessary iterative tasks and guaranteeing right usage and management of information created throughout the design process.

3.1 DFMA Methodology

Quantitative DFMA Methodologies are composed of a series of activities, information and tools systematically organized to achieve a more efficient product in terms of manufacturing and assembly [5]. The performance of these activities and tools during product design process reduces cost and product development time due to the reduction of errors and corrections at manufacturing stage [22].

Boothroyd & Dewhurst [23] and Lucas [6] methodologies are two of the most widespread DFMA methodologies taught and implemented at academic and industrial level, supported by software and successful industrial experiences, but historically, they are reactive tools, generally carried out on products in production and, at best, late on in the product production process [24] and during re-design process. This depends, in general, on the geometrical information required to implement such methodologies, but there are some activities, information and tools related to manufacturing and assembly that could be indistinctly used at different design stages. Besides, manufacturing and assembly are not only related to functional, handling and insertion analysis, design efficiencies and manufacturing cost analysis proposed by methodologies but also to assembly sequence definition, industrial capabilities, material/process analysis [25] and assembly systems.

So, the developed holistic PDDP is based on an inventory of activities, information and tools proposed by well-known DFMA methodologies taught at the B.Eng. in Product Design Engineering and structured in a logical order according to the requirements for their implementation into a PLM strategy. The Inputs, Tools (information, software and staff) and Outputs considered for each DFMA activity to be integrated into the PDDP are shown in Table 1.

Table 1. Inputs, Tools and Outputs for DFMA Activities

Activity	**Inputs**	**Tools**	**Outputs**
Evaluate Company's Capacity	Production rate required (unit/time)	Technical/Economic Viability Analysis	Definition of elements to outsource
	Facilities and machinery required	Machinery available (layout)	Report of company's capacity
	Required/available budget	Available staff (skills definition)	Processes definition (setup -cycle process)
	Required staff	Production capability	Report of Technical/Economic Viability Analysis
	Standards to meet	Databases	
		Designer	
Select Assembly System (manual, semi-automatic, automatic)	Expected production rate	Labor availability	List of requirements updated.
	Technology/processes required	Assembly system characteristics	Assembly system selected
	Initial estimate of number of components to be assembled	Assembly system selection charts	
	List of product requirements	Designer	
	Number of product versions defined.	Manufacturing Index Calculation equation	Assembly configuration defined (serial, parallel, hybrid)
	Expected ROI	Equation of working likelihood for assembly system	
	Initial estimate of the assembly cost		
Analyze Design Guidelines	List of product requirements	DFA guidelines	Product architecture
	Company's capacity	DFM guidelines	Requirements for the production processes
		Designer	
Define Assembly Sequence	Initial Bill of Materials (BOM)	Assembly Sequence Analysis (ASA) software	Assembly sequence chart
	List of assembly equipment		
	Virtual models (optional)		
	Precedence relationships	Designer	
	List of product requirements		
	Architecture defined		

Activity	Inputs	Tools	Outputs
Define essential parts and non-essential parts (Functional Analysis)	List of product requirements	B&D or LUCAS Functional Analysis (3 questions: motion, material and serviceability)	First version of the Assembly chart
	Environmental and service requirements		
	Bill of Materials (BOM)	Techniques for redesign	BOM modified
Evaluate Handling Process	Assembly sequence chart	DFMA software or TeamSET software	First version of the Assembly chart
	List of assembly equipment	B&D or LucasHandling Index Chart	
	List of product requirements	B&D or LUCAS DFA Worksheet and equations	Handling Index
	Bill of Materials (BOM)	Designer	
Evaluate Insertion Process	Assembly sequence chart	DFMA software or TeamSET software	First version of the Assembly chart
	List of assembly equipment	B&D or Lucas Insertion Index Chart	
	List of product requirements	B&D or LUCAS DFA Worksheet and equations	Insertion Index
	Bill of Materials (BOM)	Designer	
Implement design changes	DFMA guidelines	Designer	Second version of the assembly chart
	Product Architecture		
	Bill of Materials (BOM)		Redesigned product
	B&D or LUCAS Handling Analysis		
	B&D or LUCAS Insertion Analysis		
Analyze efficiency	Required efficiency	Designer	Efficiency defined
	B&D or LUCAS DFA Worksheet updated	B&D or Lucas Efficiency Equation	B&D or LUCAS DFA Worksheet finished
			Preliminary Manufacturing Index calculated
Select material and process	Company’s capacity	Chart of "Compatibility between processes and materials"	Product’s Process Chart
	Production rate (unit/time)	Non dimensional properties classification	
	List of product requirements	Modification to the "membership function"	
		Designer	
Calculate manufacturing cost index	Final product’s design	Manufacturing Index Calculation equation	Materials of the components defined
		Appearance or shape factors	Manufacturing process defined
		"Process Information Maps"	Manufacturing Index calculated
		Process capabilities	Report
		Available Facilities	
		Material and Process Costs	
		Designer	

It is important to note that the focus of the present framework is in DFMA process management, so it is not subject to any BPM language and its implementation is limited by the designer criterion, according to the nature of the product. Additionally the designer can use any other tool not here specified intending to accomplish the same goal.

3.2 Model of the proposed holistic PDDP

The proposed model is composed by five stages taken and adapted from Pugh [16]: i) Opportunity identification, ii) requirement definition, iii) conceptual design, iv) detailed design and v) production.

In order to develop the process to be implemented in PLM, authors have filtered, organized and integrated the activities, information and tools referenced in Table 1 with the purpose of having a logical and efficient process and then, they were modeled by the use of the language "Event-Driven Process Chain" (EPC) from ARIS [26].

These DFMA activities were separated and distributed through different stages established for the academic Standardized PDDP taking into account all methods, tools and information related to each activity, their convenience, and its availability at the correct time (Figure 1). Distribution of activities at each stage is illustrated in detail in the following paragraphs.

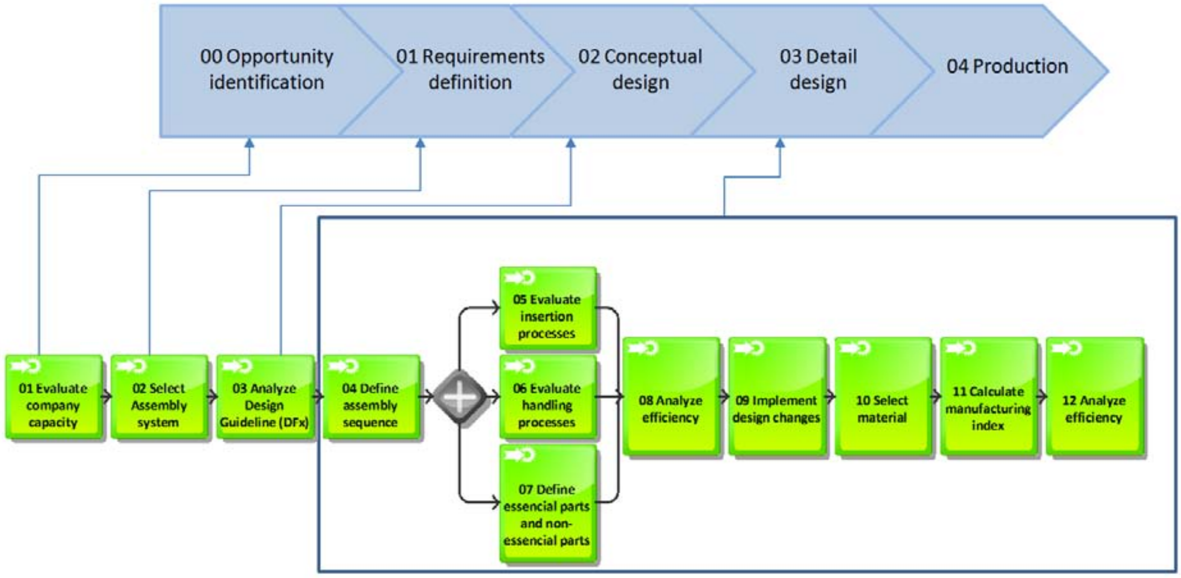

Figure 1 Distribution of DFMA activities throughout the Design Process.

In stage 0 the activity "Evaluate Company Capacity" is located between "Select opportunities" and "Assign Resources". The objective of this activity is to analyze whether the company has all the resources needed to manufacture and assemble the product and generate information that will be required in further procedures (Figure 2), just like to outsource processes or state alliances with other companies. This analysis intends to avoid future cycles in the process. It is noted that this stage is considered as the FFE.

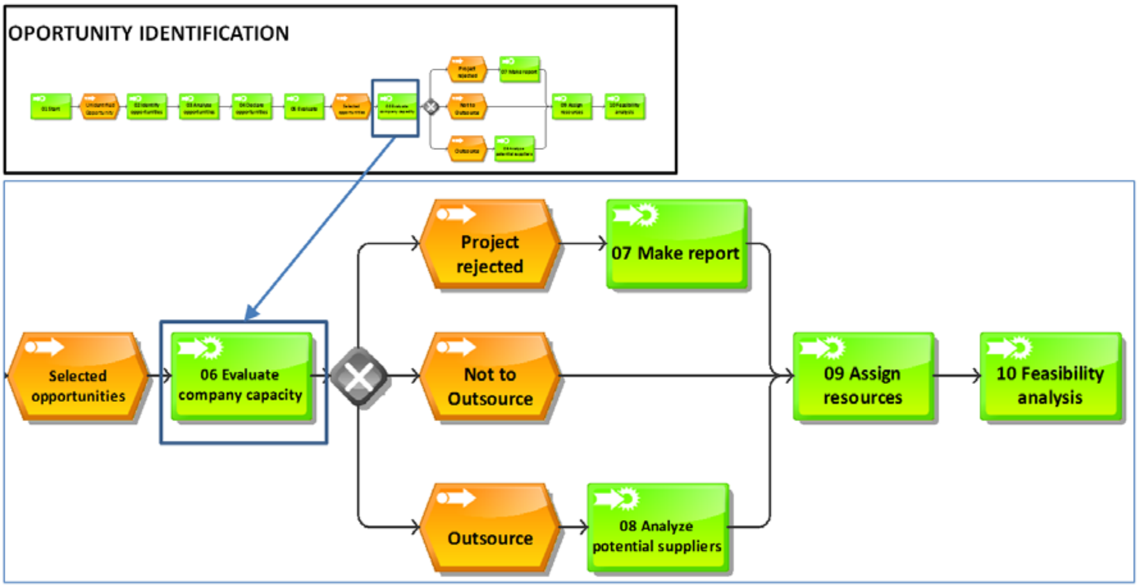

Figure 2. DFMA Activities in Stage 00.

In Stage 1 the activity “Select Assembly System” can be carried out in parallel with “Gather requirements” since in this stage all the required information is available and its early definition allows the design team to establish all the design requirements related to the type of assembly and manufacture system selected (Figure 3). The information developed here will allow limiting the concept development and the component definition in order to design a product that meets the production requirements and without unnecessary redefinition cycles or further activities.

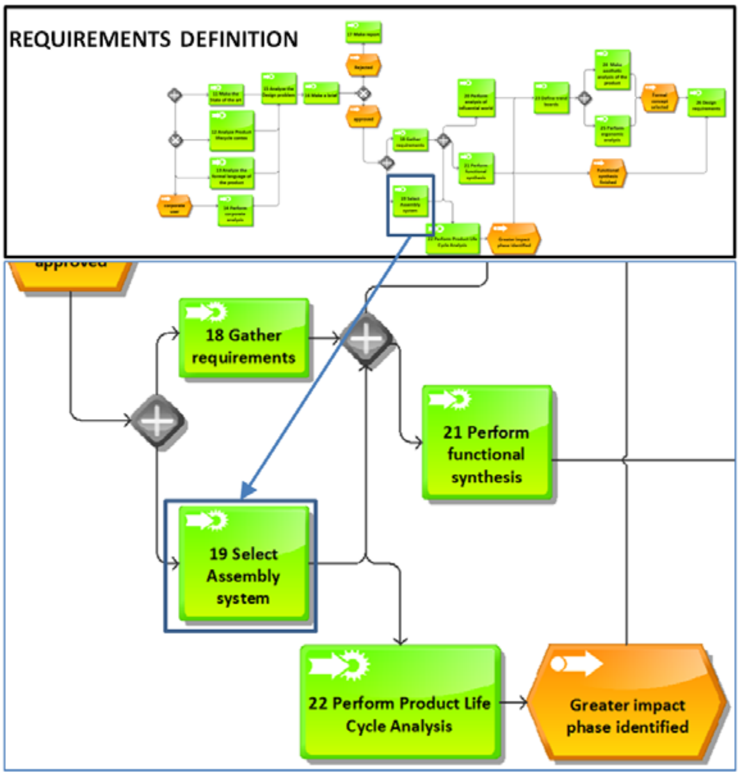

Figure 3. DFMA Activities in Stage 01.

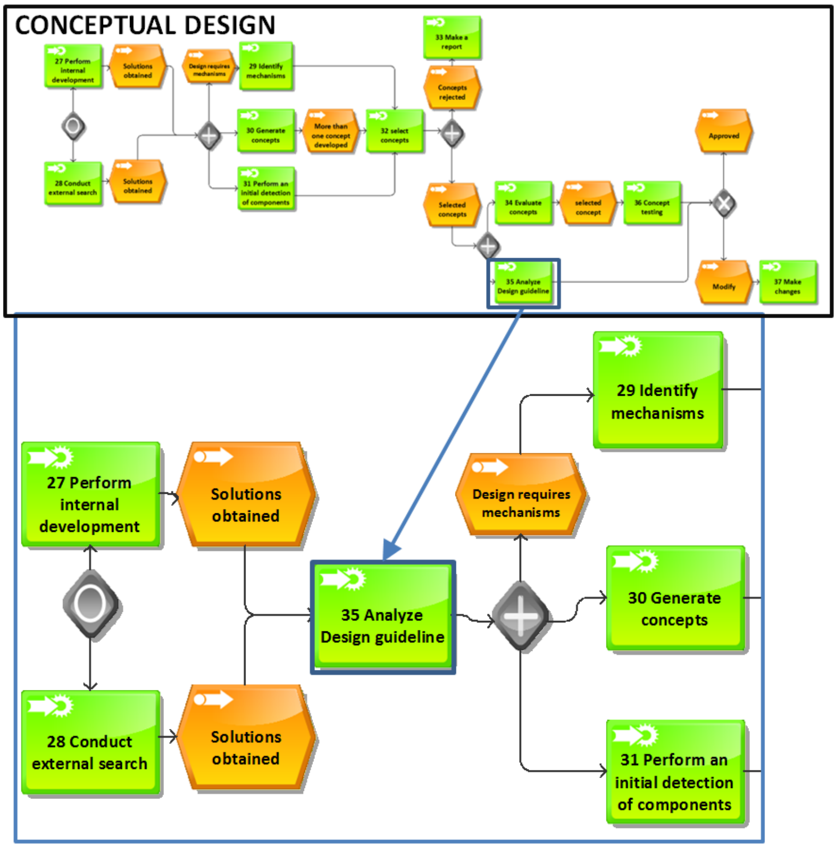

Figure 4. DFMA Activities in Stage 02.

In Stage 2 the activity “Analyze Design Guideline” is located in parallel with “Evaluate concepts” in order to take into account the DFMA considerations at the time of evaluate selected concepts. It allows the team to ensure that the selected design meets the rules proposed by the DFMA methodologies and established by the customer (Figure 4).

Stage 3 (Detailed design) comprehends most of the DFMA activities, from “Define Assembly Sequence” to the last activity of the DFMA process. “Define Assembly Sequence” is carried out once the architecture and system design is defined. This activity is followed by “Evaluate insertion processes”, “Evaluate handling processes” and “Define essential parts and non essential parts” which can be performed in parallel or sequentially according to the DFMA methodology adopted by the designer. As the assembly sequence is previously defined it is possible to evaluate the characteristics of each component in terms of manufacturing and assembly issues, in order to ensure, that each one meets all the requirements and goals proposed for the product.

These activities along with “analyze efficiency” and “implement design changes” are carried out before “CAD development”, “design validation” and “Manufacturing process design” in order to have the product as defined as possible before of starting such activities.

It is important to note that “Analyze efficiency” is done twice. First one after “Define essential and non essential parts” in order to calculate the efficiency equation with the data obtained in previous process and second one after “Calculate Manufacturing Index”. The last one is done because it is necessary to track all the changes carried out during calculations, CAD development and Design Validation. Finally “Calculate manufacturing index” is performed in order to leave absolutely defined the product in terms of components and manufacturing process to do “Life cycle analysis” and “feasibility analysis” (Figure 5).

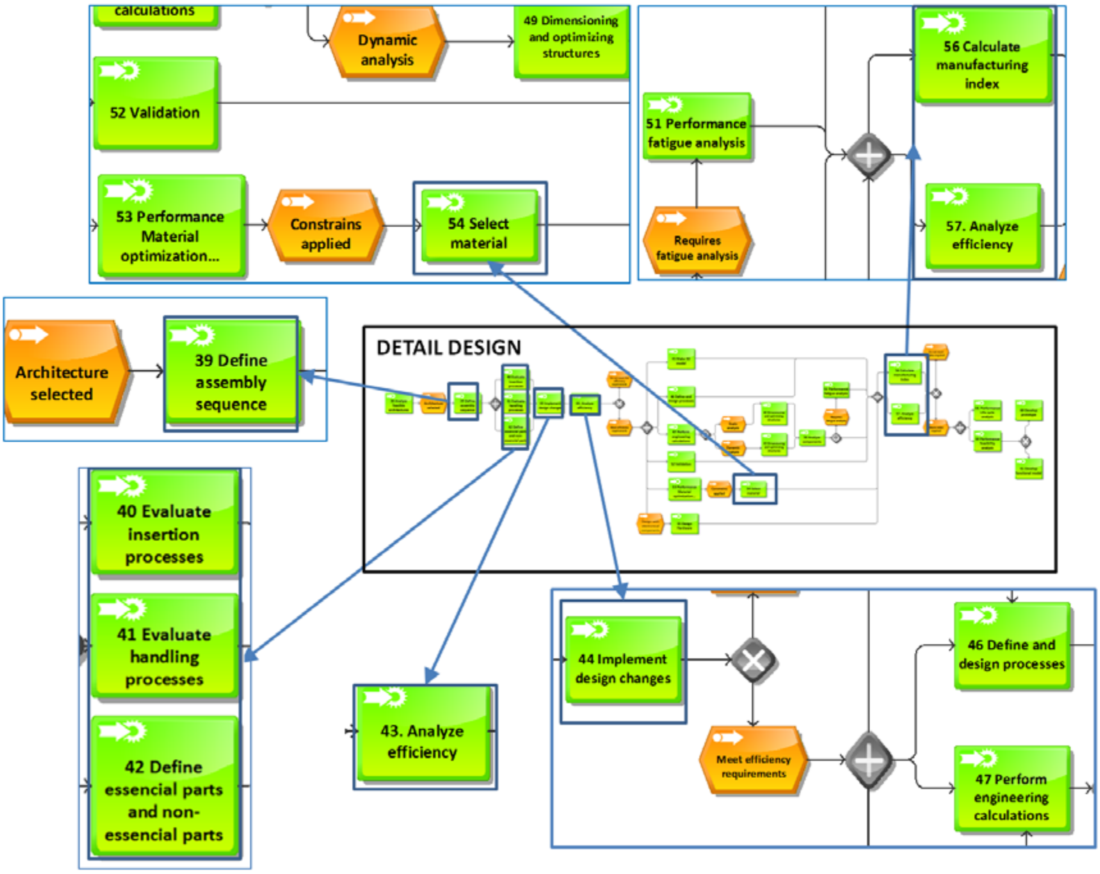

Figure 5.DFMA Activities in Stage 03

So, the DFMA activities are not considered in a sequential way through Production stage. This stage reflects the results obtained due to the implementation of such activities in the previous stages.

Since the purpose of the integration of the DFMA activities in the PDDP goes beyond the separation of the DFMA activities, some information (figures, charts and tables) related to these well-known methodologies is integrated to other activities of the PDDP as it is shown in Table 2.

Table 2. DFMA information integrated to other activities of the Design Process

Stage	ACTIVITY	DFMA INFORMATION INCLUDED
01-Requirements definition	Gather requirements	DFA and DFM rules
02-Conceptual design	Generate concepts	Chart of Shape Generation Capabilities of Process
		Process information Maps
	Initial detection of components	DFA and DFM rules
	Evaluate concepts	Basic Processing Cost Vs. Quantity per Annum Chart
03-Detail design	System definition and Feasible architectures analysis	Geometrical Complexity Chart
		Component Cost and Process Chart
		Surface Finish and Process Chart
		Chart of Tolerance Vs. Manufacturing Process
		Chart of minimum section Vs. Manufacturing Process
	Define and design process	Component Cost and Process Chart
		Chart of Shape generation Capabilities of Process
		Process information maps
		Basic Processing Cost Vs. Quantity per Annum Chart
	Perform Engineering calculations	Surface Finish and Process Chart
		Chart of Minimum section Vs. Manufacturing Process
		Chart of Tolerance Vs. Manufacturing Process Chart

In this way, DFMA methodologies could be fully integrated to standardized PDDP acting in due course and offering proper results before whole definition of the product.
The design process definition is one of the most important steps in a PLM strategy statement into a company. Once it has been defined along with other steps as indicator establishment, organizational chart development, approval flows etc, it can be uploaded in any PLM system as project templates, workflows and libraries in order to carry out engineering projects that imply new product development.

4. CONCLUSIONS AND FUTURE WORK

Most of the implementations of DFMA in PLM are directed to the development of systems and applications that support and assist a particular method or activity but at a specific part of the PDDP, conversely to the Concurrent Engineering philosophy. Besides, if a PLM strategy and its associated processes are not well established, any PLM implementation will be unsuccessful. So, the early definition of the PDDP is the first step to implement a Product lifecycle Management strategy and integration with DFX methodologies could be executed in a holistic way if their single activities and tools are separately considered.
Even if a practical case study has not been carried out, the authors argue that the separation of DFMA activities, information and tools and their incorporation to the different PDDP stages reduce unnecessary design cycles and iterations obtaining a more efficient process. Moreover, the combination of several DFMA methodologies, allows the design team to have, at the right time, a more complete and robust process with more and better tools and information that will be useful in the development of new products. Here, the figures of the adopted PDDP are intentionally left blurred since this process is exclusive “know-how” of the University and its effectiveness is in process of validation through academic case studies.
Using the language “Event-Driven Process Chain” in holistic PDDP representation is useful for its further implementation on the PLM system. At this point, as might be expected, designers would spend more time in innovative tasks than in routine processes since manufacturing process knowledge and its application would be stored in the system. Besides, this procedure supports the knowledge modeling for academic design methodologies adopted at the B.Eng. in Product Design Engineering.
This is a good approach to introduce a holistic design methodology at academic level and with current development of projects with this proposed process; better products are expected to be obtained. Future work would focus on the evaluation, validation and improvement of this proposed holistic PDDP through academic projects implementation and on integration of other different DFX methodologies, using PLM systems like support in data, information and knowledge management.

REFERENCES

[1] Baxter, M., Product Design: Practical methods for the systematic development of new products. (London: Chapman & Hall, 1995).
[2] Ullman, D., The mechanical design process. (McGraw-Hill New York, 1992).
[3] Otto, K. and Wood, K., Product design: techniques in reverse engineering and new product development. (Prentice Hall Upper Saddle River, NJ, 2001).
[4] Belay, A., Design for Manufacturability and Concurrent Engineering for Product Development. World Academy of Science, Engineering and Technology, 2009.
[5] Boothroyd, G., Product design for manufacture and assembly. Computer-Aided Design, 1994, 26(7), pp47; 505-520.
[6] Design For Manufacture and Assembly Practitioners Manual. (Lucas Engineering Systems, Ltda, 1993).
[7] ARAS-Corp., Advanced PLM Software |Enterprise Open Source|Aras [online]. Available from: http://www.aras.com/ [August, 2009]
[8] Edwards, K., Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering. Materials & Design, 2002, 23(7), pp651-656.
[9] Gomes, S., Demoly, F., Mahdjoub, M. and Sagot, J.-C., Integration of Design for Assembly into a PLM Environment. In Yan, X.-T., Ion, W.J. and Eynard, B., eds. Global Design to Gain a Competitive Edge, pp117-126 (Springer London, 2008).
[10] Howard, L. and Lewis, H., The development of a database system to optimise manufacturing

processes during design. Journal of Materials Processing Technology, 2003, 134(3), pp374-382.
[11] Spiteri, C. and Borg, J., Mobile Knowledge Management for Product Life-Cycle Design. Global Design to Gain a Competitive Edge, 2008, pp137-146.
[12] Huang, G.Q. and Mak, K.L., Design for manufacture and assembly on the Internet. Computers in Industry, 1999, 38(1), pp17-30.
[13] Qiao, G. and McLean, C., Manufacturing Information Integration in Product Lifecycle Management (PLM). In. (ASME)
[14] Wang, K., Roucoules, L., Tong, S., Eynard, B. and Matta, N., Design Knowledge for Decision-Making Process in a DFX Product Design Approach. Global Design to Gain a Competitive Edge, 2008, pp127-136.
[15] Council, D., Eleven lessons: managing design in eleven global companies. London: Design Council Gunter, P and Howard, J (2008), interview at Royal College of Art, London, 2007.
[16] Pugh, S., Total design: integrated methods for successful product engineering. (Addison-Wesley, 1990).
[17] Jauregi, E.V., Comes, L.U. and Justel, L.D., Fuzzy front end de la innovación y el pensamiento divergente y convergente. In. pp13-15
[18] Koen, P., Ajamian, G., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., Johnson, A., Puri, P. and Seibert, R., Fuzzy front end: effective methods, tools and techniques. (John Wiley & Sons, Inc, 2002).
[19] Ulrich, K.T. and Eppinger, S.D., Product design and development. (McGraw-Hill Boston, 2003).
[20] Pahl, G. and Beitz, W., Engineering design: a systematic approach. (Springer, 1996).
[21] Rothwell, R., Towards the fifth-generation innovation process. International Marketing Review, 1994, 11(1), pp7-31.
[22] Chowdary, B. and Harris, A., Integration of DFMA and DFE for Development of a Product Concept: A Case Study.
[23] Boothroyd, G., Dewhurst, P. and Winston, K., Product Design for Manufacture and Assembly. (CRC Press -Taylor & Francis, 2002).
[24] Barnes, J.C., Dalgleish, G.F., Jared, G.E.M., Swift, K.G. and Tate, S.J., Assembly Sequence Structures in Design For Assembly. In International Symposium on Assembly and Task Planning. Marina del Rey, CA, August, 1997. pp164-169
[25] Swift, K.G. and Booker, J.D., Process Selection-From Design to Manufacture. (Elsevier, Oxford, 2003).
[26] Software-AG. ARIS Express-First Free Modeling Software from Market Leader for Business Process Management | ARIS BPM Community [online]. Available from: http://www.ariscommunity.com/aris-express [August, 2009]

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