Dfx Plateform- A Holistic Approach to Design Concepts Evaluation

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Abstract
"Design for X" is commonly regarded as a systematic and proactive way of product designing to optimize total benefits over the whole product life-cycle, and to meet target quality, cost, performance and time-to-market. DFX involves different methodologies for product development therefore their results can drive to contradicted conclusions. In this paper the framework for DFX analysis was proposed. In the described solution, the various product life-cycle analysis strategies are integrated, and profit calculations relay on common denominator – the present value of net benefit. Based on the proposed framework, the DFX Platform was developed and implemented as web service, offering access to wide spectra of DFX tools and approaches. The application of the system to a few product developments carried out within cross-bordered manufacturing company showed its big positive impact on projects and their results.
Keywords: DFX, DFMA, measures of DFX, cost/benefit model

1 INTRODUCTION

To be successful in today's highly competitive global manufacturing environment, a company must be able to deliver products that customers require and at the time required by clients. These requests put tremendous pressure on engineering operations to improve an overall productivity. One way to achieve it is to increase an efficiency of individual engineering activities, e.g., through the introduction of CAX technologies (Computer Aided Design, Computer Aided Manufacturing, Computer Aided Production Planning, etc.). Another way is to improve the coordination between development activities by application of Concurrent Engineering methodology and its means supporting teamwork. In the 1990s Concurrent Engineering (CE) has been employed to improve product quality and to reduce development time and cost by resolving product, process and organizational issues at the early stage of design [1]. However, Concurrent Engineering has been defined in different ways with various implications. For instance, Garrett [2] described CE in terms of "simultaneous designing of products and defining the best way to make it in order to reduce costs and cycle times…". Similarly, Green [3] showed that CE is "an approach that involves manufacturing operations and other departmental functions through the enterprise in the design of a product". But Pawar and Sharifi [4] remind that the purpose of CE is not just to reduce time to market. It can also improve the performance of the organization as a whole. All these descriptions share the assumption that the typical objectives of CE are to (1) optimize product quality, (2) minimize manufacturing cost, and (3) shorten delivery time. In this context, the application of the "Design for X" philosophy, which is commonly regarded as a systematic and proactive designing of products to optimize total benefits over the whole product lifecycle, seems to be appropriate. DFX involves, by definition, different methodologies for product design and optimization (like Design for: Manufacturing, Assembly, Variety, Testability, Serviceability, Environment, Reliability, Utilization, etc.), which provide useful results, however, they address only specific aspects of product life-cycle. In addition, these diverse perspectives for business economics can often drive to contradicted conclusions (conflicts), what makes the evaluation of both technical feasibility and product profitability more difficult. Since different approaches use different measures for concept design evaluation (e.g. Design for Quality minimizes cost of poor quality, while Design for Assembly cuts assembly time) it is not clear how the diverse results can be judged and compared. In this context, the need for general, but unified view on design concepts evaluation is evident. As an answer, the "DFX Platform" - a holistic approach for design trade-offs analysis is proposed.

2 PROBLEM DEFINITION

In the paper the main idea of DFX Platform is explained first, and overall architecture of the solution is presented. Next, the specific framework components are given and the unified model for total benefit analysis is described.

In the past years the area of DFX has came under intensive investigation, therefore a large number of methods and tools have been developed – from simple check-lists to sophisticated knowledge-based design systems. DFX is usually carried out today in following ways:

- by cross-functional teams (multi-discipline team involved as early and often as possible)
- using specialized design manuals (which contain do's/don't rules for common processes)

• applying software tools (particular commercial software packages exist in the market), [5]

Each of these methods for implementing the DFX has certain advantages, but also drawbacks. Crossfunctional teams relay on experts from several domains who can discuss trade-offs and deal with unusual situations. However, the size of the projects, duration, or geographical dispersion in particular, may significantly reduce the productivity of such teams. Various manuals and guidelines can be extremely valuable for designers, because they usually capture the major cost drivers of company's specific products. But manuals are "passive" – they describe only known cases, and they could even never be used. Software tools allow for fast and easy analysis done by individual designers, but the interpretation of the results (scores, rating) is not always clear. Generally, all three mentioned above ways do not offer quantitative measure of the total profitability analysis. Payoffs and profits are difficult to model and quantify, but if the design alternatives are not measured correctly, the evaluation process can lead to wrong decisions [6]. Therefore, in recent years, more and more design researches see engineering design as a decision-making process, which requires rigorous evaluation of design alternatives [7], [8]. Gupta, Regli and Nau [9] proposed the solution, which evaluates different aspects of product manufacturability using multiple critiquing modules (e.g. machining, fixturing, assembly, inspection) and calculates total manufacturing cost and time. In their approach, the system is able to detect for example, a design that is inexpensive to machine, but difficult to assembly, or vice-versa. Furthermore, the multiple critiquing tools balance their individual recommendations to provide an integrated feedback to the designer. Maropouleos [10] described an approach, in which process selection tools, design-for-X methods and process planning systems are integrated into one solution. In so-called AMD architecture (aggregate, management and detailed) an evaluation of the early manufacturability of individual jobs can be executed by relating the feature geometry to knowledge about processes and resource operating parameters, and process quality cost and delivery can be calculated. Similarly, Vliet and co-workers stated that an integrated system for continues DFX design support should offer (i) coordination of the design process, and (ii) generic estimators to adequately evaluate and quantify life-cycle aspects [11], [12]. For quantification of life-cycle properties they proposed: cost, quality, flexibility, risk, lead-time, efficiency and environmental hazard. The generalized framework (shell) for manufacturability analysis is proposed in [13]. Unlike previous approaches, in this solution the user is able to choose the criterion to evaluate the manufacturability and thus is able to ensure that the most appropriate measure is selected. But, as concluded by Hazelrigg in his book [14]: the true objective of engineering design is to make money. The other design targets to (1) optimize product quality, (2) minimize cost, and (3) to be available sooner, just describe how the company maximizes its profits. The key issue of this research was to develop the means to reliably estimate and verify the costs/benefits of different design concepts at different stages of product development. Various design approaches, X-s, are collected and offered in harmonized way via DFX Platform. The role of this framework is to provide a structured workflow specifying how and when the different X methodologies can be applied, and also to unify DFX measures (to combine different DFX metrics, like direct material cost, number of articles, number of suppliers, assembly times, etc.).

3 DFX FRAMEWORK

3.1 System architecture

The most frequent design process model referred by the literature is the phase model. It divides the development process into sequential phases in time, and often introduces "gates" between the stages to control the process flow. The common phases are: project or task definition, conceptual design, detailed design, and manufacturing process definition. However, in the design practice, the phase model is not strictly followed, since it lacks the flexibility to realistically describe the product development activities. In the proposed DFX framework, the phase model is extended by functional domain – according to the project schedule different life-cycle analyses are performed in parallel. The role of this solution is (1) to provide a structured workflow specifying how and when the given X methodologies can be applied, and (2) to unify DFX measures (manage different business metrics, like direct material cost, number of articles, number of suppliers, assembly times, etc., and convert them into one, quantitative measure). The framework consists of three basic architecture layers: Information layer, Domain evaluation layer and Profit analysis layer, Figure 1.

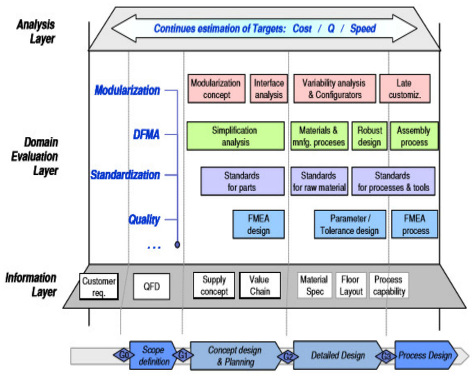


Figure 1. The general concept of DFX Platform

The Information layer stores the input data required by given engineering task, output information created in following project phases. By this module the intermediate technical results and design proposals are also transmitted between different DFX tools.

The Domain evaluation layer is designed to manage DFX approaches – the specialized methods evaluating the design concept from given product life-cycle perspective. The most common DFX approaches are:

- Modularization (maximizes external product variety),
- Standardization (minimizes the number of different article types and manufacturing. processes & tools),
- Manufacturability (assigns suitable manufacturing process and materials),
- Assemblability (optimizes assembly process),
- Late Customization (differentiates product variants by application of supplementary manufacturing steps or optional module),
- Quality (ensures product reliability and minimizes defect costs).

Application of the dedicated design approach is controlled by the Information layer of DFX framework, which invokes given tools or software packages, depending on the stage of product development. It also ensures that said approaches evaluate the design concepts in terms of cost, time and quality. The particular economic estimations and measures are transferred by the user to Analysis layer.

In **Profit analysis layer** the total cost/benefit model is constructed. The key issue in DFX Platform is to be able to reliably estimate, calculate and verify the benefits of different design options at different stages of product development. Such metrics indicating the advantages of certain option or decision must take into account and be applicable with different types of business processes and products, different stages, different DFX approaches. Even though different DFX development approaches may have different intermediate metrics, finally the design options should affect the overall operational and financial KPIs, like revenue, profit, productivity, cash flow, net present value and return of investment. The business impact model must link the intermediate product and process development measures and targets with the overall business performance measure in a way that it takes into account in an approximate but accurately enough way all significant factors (incl. risks, effects to overhead costs etc.) and interactions between the measures. In Figure 2 the relationships of business impact model are presented.

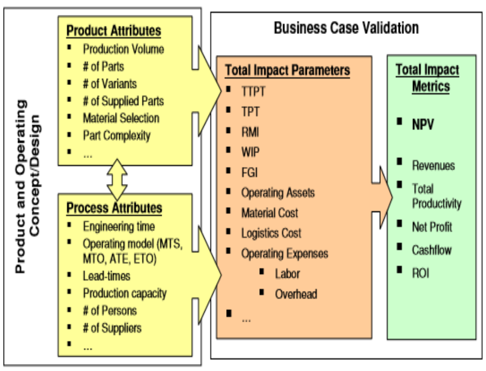


Figure 2. Business impact model relationships

As the main, quantitative measure of the total profitability analysis the present value of net benefit was selected and is calculated in analysis module. The Net Present Value (NPV) is the dynamic decision criteria – a robust financial evaluation tool to estimate a value of the investment. It is defined as the sum of the present values of the annual cash flows minus the initial investment. The annual cash flows are the net profits (difference between revenues and costs). The calculation of NPV involves identification of the size and timing of expected future cash flows generated by the investment, and determination of the interest rate. The NPV is then calculated with use of equation (1):

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_0$$

where:

t - time of the cash flow
n - total time of the project
r - interest rate
Ct - net cash flow (the amount of cash) at that point in time
C0 - capital outlay at the beginning of the investment time (t =0)

The typical DFX Platform application scenario covers: log-in to the platform web side; selection of adequate DFX approach and related tool; execution of domain analysis; evaluation of the results in terms of the domain-specific measures (e.g. material cost, assembly time, scrap ratio, etc.); and finally the total profit calculation, Figure

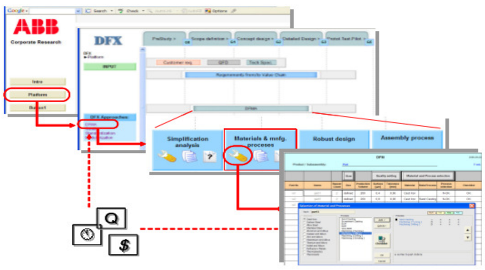


Figure 3. The general concept of DFX Platform

3.2 System implementation

Technically, the proposed solution, called DFX Platform, is implemented as a web server, which manages the different DFX approaches, controls the application of specific tools according to the phase of the development process, stores information to be accessed within any domain, and ensures consistency of cost/benefit estimations. The Platform was build up in Lotus Domino to be easily accessible in company intranet. The user invokes the web page of the DFX Platform, and follows the sequence of the analysis recommended by the system. The tools for specific DFX analyses were developed mainly as Visual Basic applications in Excel environment and are available as web services, which can be launched from the server. However, the solution allows also for off-line work. At the end of 2006, the following system components were implemented:

• DFX Platform web server – the main part of Information layer; organizes all engineering tools and approaches, provides user interface;

• DfA module – element of Domain evaluation layer; provides Simplification Analysis to reduce the product part number, analyses assembly process, calculates its time and cost;

• DfM module – element of Domain evaluation layer; assesses different manufacturing technologies and assigns the material best suited for analyzed product component;

• DfQ module – element of Domain evaluation layer; optimizes Tolerance Chain of the assembly; provides FMEA analysis for product design and production processes;

• Standardization module – element of Domain evaluation layer; calculates the optimal number of article types and unifies manufacturing operations & tools.

• Profitability analysis module – the main component of Analysis layer; reliably estimates and verifies the benefits of different design scenarios at different stages of product development; links the results of development approaches to an ultimate Net Present Value measure. Some of the exemplary tools are shown in Figure 4.

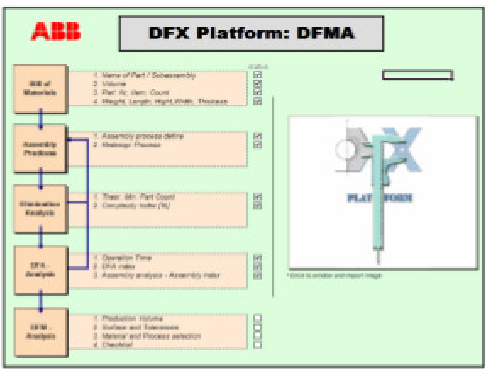


Figure 4. Examples of engineering tools available in DFX Platform

In Figure 5 the illustration of workflow on the example of DfQ approach is presented. The data between layers is exchanged in form of MS Office documents stored in database. The availability of the documents required by the system on the following design reviews is controlled by the check-lists.

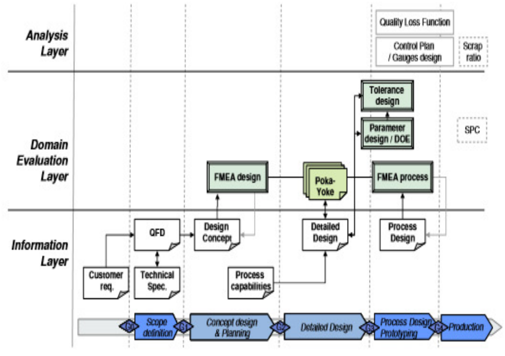
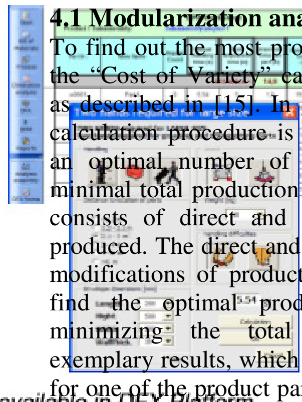


Figure 5. DfQ approach workflow

4 SYSTEM VALIDATION- A CASE STUDY

In order to illustrate the practical application of the implemented system, a case study is presented. The DFX analysis of spring mechanism powering the high voltage circuit breaker is shortly described. As different circuit breaker applications require variety of spring mechanisms, therefore it was necessary to: (1) harmonize the designs and develop a new unified product, covering different applications and energy levels, (2) reduce the production and assembly costs, and (3) improve product quality and reliability. The first target was achieved with application of Modularization approach. For second goal – the DFA and DFM tools were applied. The last objective was fulfilled by in-depth analysis of tolerance chain. All the proposed modifications to the product design were verified by NPV calculator offered in profitability analysis layer.

4.1 Modularization analysis



To find out the most profitable product design variants the "Cost of Variety" calculation method was applied, as described in [15]. In general, the "Cost of Variety" calculation procedure is based on the assumption, that an optimal number of pieces per variant relates to minimal total production cost, and total production cost consists of direct and indirect costs of all variants produced. The direct and indirect costs can change with modifications of production volume. The goal was to find the optimal production volume per variant, minimizing the total manufacturing costs. The exemplary results, which show an optimal configuration for one of the product parts are presented in Figure 6. It was calculated, that the best profitable modularization scenario is to manufacture two variants only (7kJ and 6kJ), what gives more than 25% of savings in comparison to original production costs.

TITLE:		Analysis of Opening rod		Process:	Manual sand casting	
INPUT:		7kJ	6 kJ	5,3kJ	2,6kJ	total:
Required N° of pieces:	#	875	6 000	3 650	1 500	12025
SHORT SERIES data						
# of pieces for Short series	#	875	6000	3650	300	
Variable costs /piece*	€	23,19	11,95	17,79	20,32	
Fixed costs (variety cost / year)**	€	800	1750	1250	800	
LONG SERIES data						
# of pieces for Long series	#	12000	11150	5150	1500	
Variable costs /piece*	€	18,30	11,44	16,84	17,93	
Fixed costs (variety cost / year)**	€	2150	2200	1700	1050	
Decisions:						
Size to be produced "Yes_No"***	1 / 0	1	1	0	0	
RESULTS:						
Calculated N° of pieces /Size		875	11 150	0	0	12025
Costs:						
Variable Cost /piece		23,19	11,44	17,79	20,32	
Variable Cost /Size		20 291	127 556	0	0	147 847
Fixed Costs /Size		800	2 200	0	0	3 000
					GRAND TOTAL:	150 847

Figure 6. The calculation results for one product article

4.2 DFMA analysis

In second analysis stage, the manufacturing and assembly aspects of new product design were taken into account. Each component in the assembly was examined with support of dedicated DFA and DFM tools. This study started with simplification analysis aiming to reduce the number of product parts. As a result one could state, that potentially about 50% of components might be eliminated, as shown in Figure 7, for example.

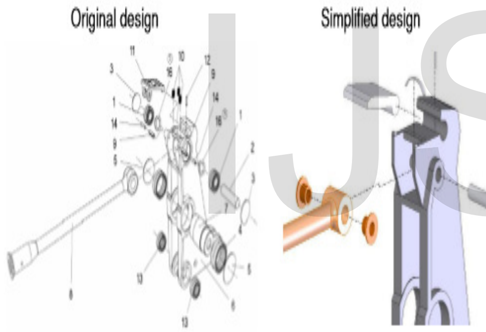


Figure 7. An exemplary result of DFA analysis.

Next, the manufacturing aspects for all product components were further studied, and the most cost efficient manufacturing technologies were assigned based in the production scale, Figure 8.

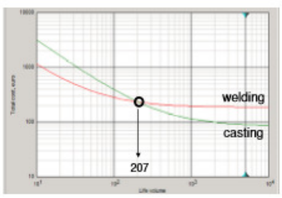


Figure 8. The break-even calculation for one of the product articles

4.3 Quality Approach

In order to improve the quality of analyzed product as well as increase its robustness, the Quality tools offered by DFX Platform were involved. In particular Tolerance analysis was run for the selected geometry and shape tolerances stated on drawings. The study allowed significant increasing of production yield, by optimizing components dimension tolerances, Figure 9.

Figure 9. Tolerance chain analysis tool in DFX Platform

4.4 Total profitability analysis

One of the key advantages of the DFX Platform is the possibility to reliably estimate the profit of analyzed product concept. The main challenge for the analysis layer was to be able to link the development approaches and the different product and value chain design options with ultimate NOV measure in a way that is reliable and comprehensive, but still simple enough to be practically applicable. The business impact coming from different DFX analyses is sum up and total cost/benefit figure is calculated, Figure 10. In this way, different product concepts can be compared over the whole life-cycle.

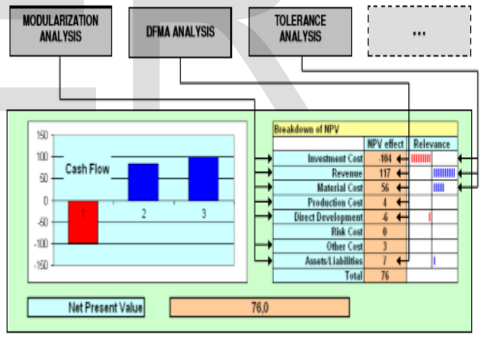


Figure 10. Total cost/benefit analysis

5 SUMMARY

Most of today's DFX methods and tools (software packages, manufacturing guidelines, check lists, etc.) consider product and process design in unilateral way mainly, e.g. manufacture- or assembly centric. This research proposed the framework, which integrates wide spectra of product life-cycle analysis strategies, and involves trade-offs between different design objectives and business profitability measured by present value of net benefit. Based on the proposed framework, the DFX Platform was developed. The solution was designed as a web service, which manages the different design approaches, controls the application of specific tools according to the phase of the development process, transfers the information between and within engineering domains and ensures consistency of cost/benefit estimations. The practical solution supporting proactive, profit oriented design, was implemented and successfully applied to a few product development projects carried out within crossbordered manufacturing company, and showed its big positive impact on projects and their results. There was also very positive feedback from its end users. It was especially noticed, that design concepts generated "under auspices" of DFX Platform incorporated equally a vast spectrum of product life-cycle aspects, what resulted in higher product quality and lower production costs. The seamless integration with current decision reviews is expected by the users, therefore as a next step in development of DFX Platform the integration of the tools with the CAD systems is planned.

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