# DFX Platform for life-cycle aspects analysis

Piotr Ciechanowski[1a], Lukasz Malinowski[a] and Tomasz Nowak[a]

[a]ABB Corporate Research, Poland.

**Abstract.** "Design for X" is commonly regarded as a systematic and proactive designing of products to optimize total benefits over the whole product life span (fabrication, assembly, test, procurement, shipment, delivery, operation, service, disposal), and meet target quality, cost, performance and time-to-market. DFX involves different methodologies for product design and optimization (like Design for: Manufacturing, Assembly, Variety, Serviceability, Environment, Reliability, Utilization, etc.), which provide useful results, however, they address only specific aspects of product life-cycle. In addition, various perspectives for business economics can often drive to contradicted conclusions, what makes the evaluation of both technical feasibility and product profitability more difficult. 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. This approach allows covering of all phases of a product life cycle not excluding e.g. complex environmental aspects. Based on the proposed framework, the DFX Platform was developed and implemented as a web service. 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, measures of DFX, life cycle, cost/benefit model

## 1 Introduction

Today's highly competitive global manufacturing environment requires continous improvement of producers efficiency. One way to achieve it is to increase an efficiency of individual engineering activities, e.g., through the introduction of IT technologies. Another way is to improve the coordination between development activities by application of Concurrent Engineering (CE) methodology and its means for supporting teamwork. 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 life-cycle, seems to be appropriate.

[1] Dr Piotr Ciechanowski; ABB Corporate Research; ul. Starowislna 13A, 31-038, Kraków, Poland; piotr.ciechanowski@pl.abb.com, tel. +48 12 4244114

DFX involves, by definition, different methodologies for product design and optimization (like Design for: Manufacturing, Assembly, Variety, Testability, Serviceability, Environment, Reliability, Utilization, Recycling, etc.), which provide useful results however, they address only specific aspects of product life-cycle.

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 those 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

### 2.1 Approaches to DFX methodologies integration

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’ts rules for common processes)
- applying software tools (particular commercial software packages exist in the market), [1]

Each of these methods for implementing the DFX has certain advantages, but also drawbacks. 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. Therefore, in recent years, more and more design researches see engineering design as a decision-making process, which requires rigorous evaluation of design alternatives [4], [16].

Gupta, Regli and Nau [3] 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 [7] 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 [15], [14]. 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 [5]: 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.

### 2.2 DFX and product life cycle phases

Today's integrated DFX tools consider mainly production phase of a product life span. However there are other aspects, which need to be covered. Design for environment (DFE), together with Life Cycle Assessment (LCA) - its most powerful instrument, is one of the most difficult to integrate with other DFX tools, which are much more related to economic benefits [8]. Life time environmental impact can be expressed in terms of price of pollutions treatment (Tellus and EPS methods) [12], [11], however these costs would not be covered directly by a producer. Nevertheless LCA can be easily integrated into the DFX framework by taking into account customer willingness to pay for "green product" [6]. More and more producers are forced (WEEE, Waste Electrical and Electronic Equipment - EU Directive) to take back their product at the "end of life" therefore Design for Recycling is the most important part of the DFE.

Rising warranty costs focus attention on the issue of Design for Serviceability [2]. Service Mode Analysis and probabilities of failure modes will be the key issues in warranty cost evaluations.

Design for Performance and Design for Compliance would complete other required design aspects related to operational and "end of life" life cycle phases.

### 2.3 The research goal

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, assembly times, failures probability, etc.).

# 3 DFX Framework

## 3.1 System architecture

In the proposed DFX framework, a typical 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 and convert them into one, quantitative measure.

The framework consists of three basic architecture layers: Information layer, Domain evaluation layer and Profit analysis layer, Fig. 1.

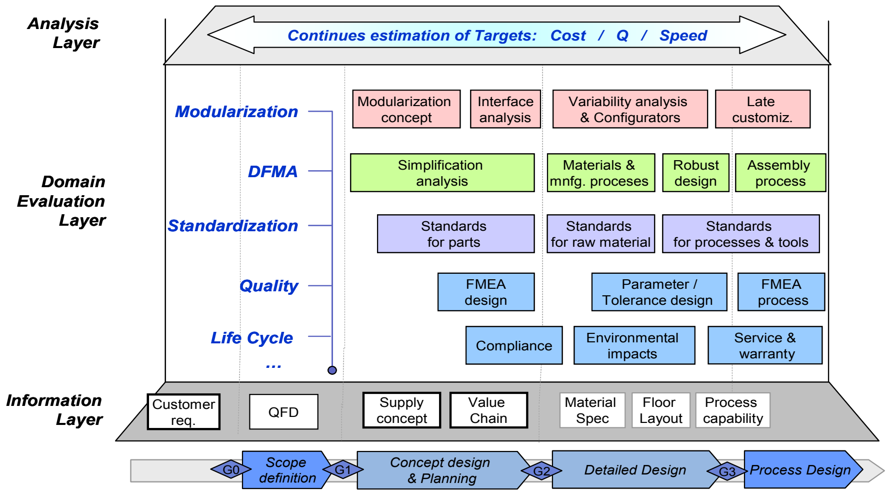


**Figure 1**. The general concept of DFX Platform

The **Information layer** stores the input data required by given engineering task and 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 mnfg. 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).
- Life Cycle – operation & "end of life" (minimizes service/warranty costs, minimizes take-back obligations 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 to Analysis layer.

In **Profit analysis Layer** the total cost/benefit model is constructed. In analysis module the present value of net benefit is calculated - as the main, quantitative measure of the total profitability analysis. The Net Present Value (NPV) shows the difference between present value of cash inflows and present value of cash outflows.

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

where:
t - time of the cash flow
n - total time of the project
r - interest rate
$C_t$ - net cash flow (the amount of cash) at that point in time
$C_0$ - capital outlay at the beginning of the investment time (t = 0)

The typical application scenario covers: log-in to the DFX 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) and finally the total profit calculation.

### 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, transfers information between and within domains, and ensures consistency of cost/benefit estimations. 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 are developed mainly as web services, which can be launched from the server. However, the solution allows also for off-line work.

## 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.

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, (3) improve product quality and reliability, as well as (4) minimize warranty and “take back” costs.

The first target was achieved with application of Modularization approach. For second goal – the DFA and DFM tools were applied. Third objective was fulfilled by in-depth analysis of tolerance chain, while the last one with use of Life Cycle Cost (LCC) tool. 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 [9]. The goal was to find the optimal production volume per variant, minimizing the total manufacturing costs. It was calculated, that best profitable modularization scenario is to manufacture two variants only, out of four, what gives more than 25% of savings in comparison to original production costs.

### 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 37% of components might be eliminated.

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

### 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.

### 4.4 Operation & “end of life” analysis

Product design optimization related to life phases after “factory gate” were limited to warranty and “take back” obligations.

Failure costs were calculated according to following formula [10]:

$$Cost_{failure} = (C_{Repair} * f_{nonstop} + C_{Consequence})\, f_{stop} \qquad (2)$$

where:

$Cost_{failure}$ = Total costs of failures

$C_{Repair}$ = Repair and/or replacement cost

$C_{Consequence}$ = Consequence costs i.e. standstill cost from failure

$f_{stop}$ = Number of Stopping failures in life time

$f_{nonstop}$ = Number of Non-stopping failures in life time

LCC tool supports failures modes calculation as well as recycling and disposal options. Average service time and cost can be reduced 25% due to proposed greasing system modifications.

Decommissioning cost can be minimized due to reduced number of parts and use of recyclable material eliminating disposal alternative.

### 4.5 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 business impact coming from different DFX analyses is summed up and total cost/benefit figure is calculated, In this way, different product concepts can be compared over total life-cycle.

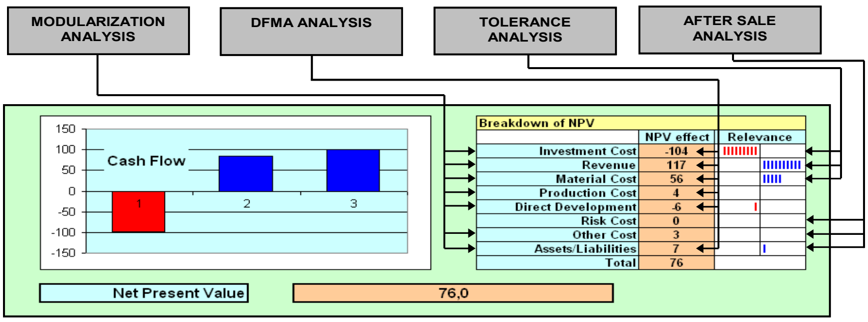


**Figure 2.** Total cost/benefit analysis

## 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 manages the different design approaches from whole life-cycle (including "end of life") perpective, 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 cross-bordered manufacturing company, and showed its big positive impact on projects and their results. 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, lower production and after sell costs.

## 6 References

[1] Boothroyd G., Dewhurst P. and Knigth W. Product design for manufacture and assembly, 1994 (M. Dekker, New York).
[2] Bryan, C., Eubanks, C.F., Ishii, K. Design for Serviceability Expert System. ASME Computers in Engineering. August 1992, San Francisco, CA. Vol.1. ISBN 0-7918-0935-8. pp. 91-98.
[3] Gupta S.K., Regli W.C. and Nau D.S. Integrating DFM with CAD through Design Critiquing. Concurrent Engineering: Research and Applications, 1994, 2(2), pp. 85-94.
[4] Hazelrigg G. An Axiomatic Framework for Engineering Design. ASME Journal of Mechanical Design, 1999, 121, pp. 342-347.
[5] Hazelrigg G. Systems Engineering: An Approach to Information-Based Design, 1996 (Prentice Hall, New York).
[6] Hunkeler D., “Life Cycle Profit Optimization”, International Journal of LCA vol. 5 (1), pp. 59-62, 2000.
[7] Maropoulos P., Bramall D. and McKay, K. Assessing the manufacturability of early product design using aggregate process models. Journal of Engineering Manufacture, 2003, 217, pp. 1203-1214.
[8] Norris G. A., “Integrating Life Cycle Cost Analysis and LCA”, International Journal of LCA vol. 6 (2), pp. 118-120, 2001.
[9] Nowak T., Chromniak M. The Cost of Internal Variety: A Non-Linear Optimization Model. In Proceedings of International Design Conference – Design, Dubrovnik, 2006.
[10] Ravemark D., LCC/LCA experience - developing and working with LCC tools. ABB 2004, available at: http://www.dantes.info/Publications/publications_date.html
[11] Steen B., “A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – Models and data of the default method, CMP report 1999
[12] Tellus Institute, “The Tellus Packaging Study”, Tellus Institute Boston, 1992, available at: www.epa.gov/opptintr/acctg/rev/7-10.htm
[13] Tharakan P., Zhao Z. and Shah J. Manufacturability evaluation shell: A re-configurable environment for technical and economic manufacturability evaluation. In Proceedings of DETC03/DFM-48155, Chicago, 2003.
[14] Vliet J., Luttervelt C. and Kals H. An integrated system architecture for continues DFX design support. In Proceedings of 9th International Machine and Production Conference, UMTIK, Ankara, 2000.
[15] Vliet J., Luttervelt C. and Kals H. Quantification of life-cycle aspects in a DFX context. In Proceedings of 9th International Machine and Production Conference, UMTIK, Ankara, 2000.
[16] Wassenaar H. J. and Chen W. An Approach to Decision-Based Design. In Proceedings of DETC01/DTM-21683, Pittsburgh, 2001.