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# LIFE CYCLE DESIGN FOR COMPANIES – SCALING LIFE CYCLE DESIGN METHODS TO THE INDIVIDUAL NEEDS OF A COMPANY

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## Abstract

To successfully implement methods in industry, they must be adapted to the company's products, its design processes, its organization, and its surroundings. Analyzing these company-specific circumstances allows one to identify the company's needs for methodical support. Once these needs are known it is possible to select an appropriate method. If different methods support the same task (lead to similar results) and are applicable by product developers, then the effort for carrying out the method and the accuracy of the achievable result are the most important distinguishing criteria. In many cases a reduction in effort implies a reduction in the results' accuracy. This is not always negative, since in a lot of cases only rough results are necessary. If the effort for carrying out the method is reduced without sacrificing the accuracy of the results, then this is called method improvement. The paper presents two examples of how different methods for life cycle design can be scaled and improved.

From these results a portfolio is developed which allows for the structuring of different methods. Furthermore, six general scaling and improvement techniques are derived, which are used throughout the examples. The paper is a first attempt to open a discussion on method selection and improvement.

*Keywords: integrated engineering and introduction of methods in industry, design for the environment, eco design, green product development, sustainable design*

## 1 Introduction

On account of the global market and the higher expectations of the customer, the companies are facing a tougher competition. The time-to-market time is getting shorter while the products become more diversified and complex. Additionally, the quality must be better even when the product becomes cheaper. This leads to a rising time and cost pressure for the product development process and the product developer. In this competitive environment companies are facing the problem of integrating environmental aspects in their products. Motives for integrating environmental aspects are in most cases legal force, customer demands, cost reduction or the "free will" to increase the diversity of the company/brand's image, thus giving them a competitive edge, and therefore, a unique selling proposition (USP) [1].

For six years the Collaborative Research Center (CRC) 392 "Design for Environment – Methods and Tools" has been working in the field of life cycle design. During these years of research, new models, methods, tools, and approaches towards life cycle design have been developed, adopted and applied in both education and industry. Based on the experiences of the CRC 392, an approach to the ideal process of life cycle design in industry and education has been proposed [2].

Therefore, the problem is not the lack of methodical support for life cycle design, rather that of selecting the appropriate methods to meet the individual needs of a company. Most companies require methods to be easy and quick to use, and of course, that they lead to the right results. The problem, in most cases, is that with decreasing work effort, the accuracy of the results decreases as well. Therefore, a compromise between the effort and the accuracy must be made. Our experience is that, in general, smaller companies with fewer resources in the R&D department usually use fewer methods than larger companies. Therefore, they need simpler and quicker methods. Which methods fit best to the company's needs depends on many factors, such as the company's products, its design processes, organization, and environment [3].

## 2 Method-selection portfolio

How does a product developer normally select a method? To answer this question a different area of method application is looked at. The stress calculation, or more specifically, the calculation of the necessary shaft diameter depending on the load is used as an example. In general three different methods can be found: the rough estimation formula[1], the German industry standard DIN 743-1 : 2000-10 and the finite element method (FEM). Which method does the product developer use? This depends on the necessary accuracy of the results. In general for a 'quick and dirty' result the product developer selects the rough estimation formula. If a more accurate result is needed the product developer has to put in more effort and selects the VDI guideline. The most accurate result, however, would be achieved using FEM calculation - but that also requires the most effort.

From this example two main criteria for selecting an appropriate method are identified. One criterion is the "accuracy of results" and the other is the "effort for carrying out" the method. These two dimensions can be used to build up a method-selection portfolio, which structures the methods and supports the product developer in selecting the appropriate method. To illustrate this, the methods described above for calculating the diameter of a shaft are qualitatively placed into the portfolio (Figure 1).

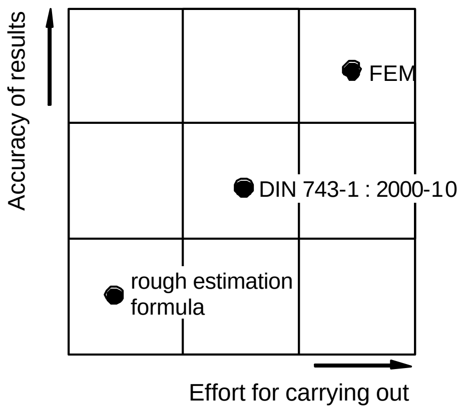


Figure 1. Method-selection portfolio for calculating the diameter of a shaft

[1] $d = 5{,}9 \cdot \sqrt[3]{M_T}$ , for $t = 25$ N/mm² (d in [mm] and $M_T$ in [Nm])

From the portfolio it can be seen that the methods for calculating the diameter of the shaft are scaled over the “effort for carrying out” and “the accuracy of the result”. And that for more accurate results often more sophisticated and effort-intensive methods are needed. Depending on the problem/goal (required accuracy of the results) and constraints (effort for carrying out), the product developer can select the appropriate method.

It is also often advisable to carry out a rough estimation of the shaft in order to identify the peak load, and finally, to optimize those peaks by carrying out a detailed analysis.

This approach will be taken and transferred to life cycle design in order to support method selection and supply the product developer with appropriate methods.

# 3 Methods for life cycle design

In the beginning desk research was carried out. It consisted of a literature study, an internet search and email inquiries. Through this research a pool of over 100 methods and tools for life cycle design was established. A small description of the methods including the goal, the procedure and the results was made. Based on this, the necessary methodological support for the product developer for life cycle design was divided into the following three areas:

- Information resources about environmental data of materials; design strategies, rules and guidelines; collection of examples and solutions; overview of laws and regulations; etc.
- Environmental impact assessment methods can be divided into the areas of focus (whole life cycle or single life cycle phases) and results (qualitative and quantitative)
- Extended conventional product development methods for analyzing the product, supporting decisions, considering market aspects etc.

The most promising methods were applied to at least one consumer product. The results were rather disappointing. Sometimes it was not clear what to do or how the methods work; some methods were still under development or not used any longer, others had a poor benefit/effort ratio. Therefore, the result was that only a handful of methods are suitable.

The use of the method-selection portfolio to exemplarily structure some methods for life cycle design showed that for some problems methods exist - for some more, for others fewer. If not enough methods exist the product developer has the problem of not being able to select an appropriate method for the problem and its constraints.

# 4 Examples of different scaling approaches

In this section two examples are used to illustrate the method-selection portfolio and different approaches for scaling methods. From these examples theoretical possibilities for scaling methods are derived in section 5.

## 4.1 Environmental impact assessment methods

To assess the environmental impacts of a product, various methods have been found to be useful. Life cycle assessment (LCA), for example, provides more accurate results than the MET Matrix, but also requires more effort to carry out. Between these two methods, various abridged assessment methods, like ready-made Eco-indicator 99 (EI 99) scores, are developed. Therefore, similar to the diameter calculation of the shaft, different methods are used for different problems and boundary conditions.

**MET matrix**

The MET matrix [5] is suitable for sensitizing the designer to environmental issues and can be used in a workshop. Even non-experts like students achieve a good understanding of a product's environmental impacts using the MET Matrix. The MET Matrix is fast to use but the results are less accurate and mainly qualitative.

**Eco-indicator 99**

A quantitative method is a rough estimation using ready-made Eco-indicator 99 (EI 99) scores [6]. This method is based on specific factors, which are calculated in previous LCAs. The factors are normalized to a specific unit, e.g. kg, liter, m³, kWh view or m², and are then multiplied by a material weight, material volume or energy consumption to calculate the environmental impact. Despite some criticism from the scientific point of view, due to the inability to backtrack and the lack of accuracy, this method is well-suited for life cycle design to identify and prioritize the product's weak-points on the material and process levels [7]. Ready-made EI 99 scores are being successfully used in projects and education at the Darmstadt University of Technology and TU Delft. The advantage of these methods is that they do not require great expertise, time and money to identify environmentally relevant materials and processes.

**Life cycle assessment (LCA)**

Life cycle assessment (LCA) is, of these three, the most accurate method for assessing environmental impacts, but is usually too labor-intensive to carry out during the product design. Nevertheless, it is advisable to carry out LCAs for materials or process which environmental impacts are not well known, and for establishing company-specific checklists or guidelines. Since an LCA is under a lot of circumstances too complex and time-consuming for a company to carry out, co-operative projects with research institutes or universities are helpful.

With these methods the diagonal of the matrix is filled so the product developer has the chance to select a method appropriate to the problem and boundary condition. Nevertheless, much research is being invested in this area. But why? The answer is simple: the existing methods must be improved by "breaking out of the diagonal" to achieve a higher accuracy with less effort. Based on this idea two new methods are currently being developed in the CRC 392.

**Design Environment of CRC 392**

One research approach is the Design Environment of the CRC 392 which has been developed with the goal to achieve results as accurate as an LCA but with less effort. It is a good tool for supporting the designer during the detailed design (Figure 2). The Design Environment enables the designer to carry out an LCA simultaneously during its detailed design in a CAD system. A first prototype was implemented and evaluated using a water cooker [8]. The results show that the Design Environment is a suitable tool to efficiently and effectively support the designer during the detailed design. Nevertheless, to successfully use the Design Environment in daily design work, more processes must be added. Additionally, the runtime and the stability of the system must be improved.

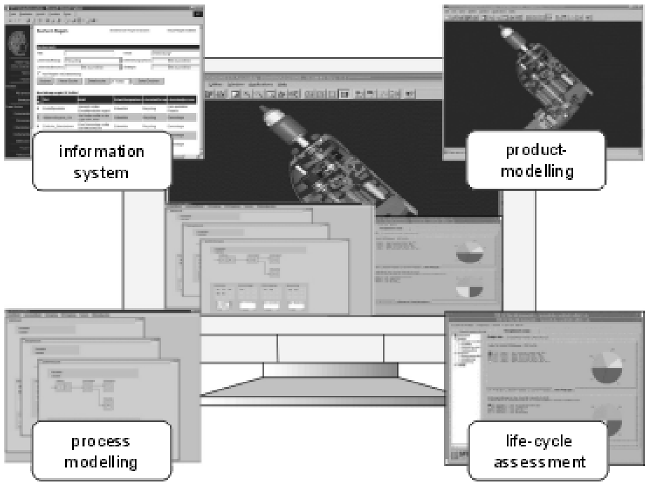


Figure 2. Design Environment of CRC 392

**Use phase analysis matrix**

Another approach is the use phase analysis matrix [9]. This matrix is specialized for the use phase, with a specific structure and checklist. Due to the limitations for the use phase, it is possible to achieve a higher accuracy of results with the same amount of effort.

These methods are all placed in the method-selection matrix (Figure 3). It can be seen that, besides the existing "diagonal methods", research work is aimed at improving these methods. Looking at these examples, different scaling possibilities can be identified. A scaling method on the diagonal fields is achieved by using different methods with different procedures. In the case of the design environment, the LCA method is improved by combining different methods and using computer support with the goal of reducing the effort. The use phase analysis matrix is specialized for a specific case (here the use phase) in order to achieve more accurate results.

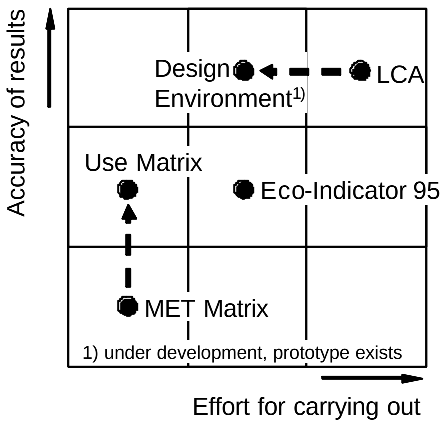


Figure 3. Method-selection portfolio for environmental impact assessment methods

## 4.2 Eco Quality Function Deployment (Eco-QFD)

The main goal of the Eco-QFD [10] is to identify the correlation between the customer/ecological demands and the product characteristics. This is done using the Eco House of Quality (Eco-HoQ) (Figure 4). The problem with the HoQ in general is that it is very time-consuming to fill in the whole matrix and that the results are in most cases "nothing new" (at least after filling in the matrix and establishing an opinion during the process).

Nevertheless, the results gathered while filling in the matrix and the discussion about the correlation between demands and product characteristics are very important. So in most cases, the way, and not the result, is the goal. In using the HoQ for identifying the correlation, the problem arises that the customers and ecological demands are sometimes contradictory. Such contradictions must be identified and resolved, since two contradictory demands cannot be fulfilled by one product. Therefore, it is necessary to first carry out the Contradiction Matrix (Figure 5) and resolve these.

| 9 strong Correlations<br>3 medium Correlations<br>1 weak Correlation | | | | | | | | Product characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Primary | | | Technical characteristics | | | | | | … | | | |
| | | | | | Secondary | | | Drive | | | Juice production | | … | Housing and attachments | | | |
| | Primary | Primary weighting | Secondary | Secondary weighting | Tertiary | Tertiary weighting | Total weighting | Motor performance | Efficiency (motor+gears) | … | Press tip | … | … | Gloss | … | Unweighted sum | Weighted sum |
| Consumer Demands | Operation (16%) | 0,16 | Pressing (60%) | 0,6 | Operational with one hand | 0,2 | 0,02 | | | | | | | | | 0 | 0,0 |
| | | | | | Automatic start/stop | 0,4 | 0,04 | | | | | | | | | 0 | 0,0 |
| | | | | | Steadiness | 0,2 | 0,02 | | | | | | | | | 0 | 0,0 |
| | | | | | Long cord | 0,1 | 0,01 | | | | | | 9 | | | 9 | 0,1 |
| | | | | | Low noise generation | 0,1 | 0,01 | | | | | | | | | 0 | 0,0 |
| | | | Cleaning (40%) | 0,4 | Dishwasher-safe | 0,5 | 0,03 | | | | 3 | 3 | | 1 | | 7 | 0,2 |
| | | | | | ... | ... | ... | | | | | | | | | | |
| | Press perfor-mance (24%) | 0,24 | Press yield (100%) | 1 | High juice yield | 0,4 | 0,10 | 3 | | | 9 | 3 | | | | 15 | 1,4 |
| | | | | | Fast juice extraction | 0,6 | 0,14 | 9 | 1 | | 9 | 1 | | | | 20 | 2,9 |
| | ... | ... | ... | ... | ... | ... | ... | | | | | | | | | | |
| | | | | | Sum absolute consumer demands | | | 12 | 1 | | 21 | 7 | 9 | 1 | | | |
| | | | | | Sum weighted consumer demands | | | 3,0 | 2,7 | | 3,8 | 0,6 | 0,1 | 0,4 | | | |
| Environmental Demands | Environmental demands (100%) | 1 | Production of raw materials (20%) | 0,2 | Large amount PP | 0,3 | 0,06 | | | | | | | 3 | | 3 | 0,2 |
| | | | | | Large amount recycling mat. | 0,4 | 0,08 | | 1 | | | | | 3 | | 4 | 0,3 |
| | | | | | Small amount copper | 0,1 | 0,02 | 9 | | | | | 9 | | | 18 | 0,4 |
| | | | | | Small amount PVC | 0,1 | 0,02 | | | | | | 9 | | | 9 | 0,2 |
| | | | | | Used regenerative raw materials | 0,1 | 0,02 | | | | | | | | | 0 | 0,0 |
| | | | Use (60%) | 0,6 | Optim. Press tip (Efficiency) | 0,7 | 0,42 | 3 | | | 9 | | | | | 12 | 5,0 |
| | | | | | .... | ... | ... | | | | | | | | | | |
| | | | ... | ... | .... | ... | ... | | | | | | | | | | |
| | | | | | Sum absolute environmental demands | | | 12 | 1 | | 9 | 0 | 18 | 6 | | 97 | 10,7 |
| | | | | | Sum weighted environmental demands | | | 1,4 | 0,1 | | 4,3 | 0,5 | 0,4 | 0,8 | | | |
| | | | | | Total absolute sum | | | 24 | 2 | | 30 | 7 | 27 | 7 | | | |
| | | | | | Total weighted sum | | | 4,4 | 2,8 | | 8,1 | 1,2 | 0,4 | 1,1 | | | |

Figure 4. Eco-HoQ of Eco-QFD for a citrus press (following [10])

One possibility to condense the method would be to just carry out the contradiction matrix, since the information gathered by this method is important. The product developer should be aware of contradictions between market and environmental demands. The marketing aspect focuses on selling arguments whereas the environmental and market demands are aligned and even reinforce each other. Carrying out the contradiction matrix results in a method with low effort and accuracy.

Another way to reduce the effort in carrying out the Eco-QFD exists, e.g., for the weighting procedure of the customers and environmental demands. Instead of the time-consuming tedious pair-wise comparison, the demands must be grouped together on a primary, secondary and tertiary level (Figure 4). In doing so, it is possible to first weight the demands on the primary level. After this, the sub-demands on the secondary level within one primary level demand must be weighted against each other. After this has also been performed for the demands on the tertiary level, the total weighting factor for one demand is calculated by multiplying the factors from the primary, secondary and tertiary level with each other. This weighting procedure is, of course, less accurate but also less labor-intensive, since only the demands on the same level within one subgroup are weighted against each other. The impact of the different weighting procedures in the end result and the revealed conclusions must be evaluated. The question in this case is: Do the final requirements drawn from the Eco-QFD differ considerably when different weighting procedures are used?

2 strongly pos. correlation
1 positive correlation
-1 negative correlation
-2 strongly neg. correlation

| | | | Primary | Environmental Demands | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Production of raw materials | | | | | Pro-duction | | Use | | ... |
| | | | Secondary | Large amount PP | Large amount recycling mat. | Small amount copper | Small amount PVC | ... | Omission of smooth surface | Fewer splices | Optimized press tip (efficiency) | Automatic start/stop | ... | ... |
| | Primary | Secondary | Tertiary | | | | | | | | | | | |
| Consumer Demands | Operation | Pressing | operational with one hand | | | | | | | | | 2 | | |
| | | | Automatic start/stop | | | | | | | | | | | |
| | | | Steadiness | | | | | | | | | | | |
| | | | Long cord | | | -2 | -2 | | | | | | | |
| | | | .... | | | | | | | | | | | |
| | | Cleaning | Dishwasher-safe | | | | | | | 1 | | | | |
| | | | Simple disassembly (Cleaning) | | | | | | | | | | | |
| | | | ... | | | | | | | | | | | |
| | Press-performance | Press yield | High juice yield | | | | | | | | 2 | | | |
| | | | ... | | | | | | | | | 2 | | |
| | ... | ... | ... | | | | | | | | | | | |

Figure 5. Contradiction matrix of Eco-QFD for a citrus press (following [10])

Masui, Sakao et al. stated that it might be possible to derive a predefined set of environmental requirements and environmental product properties, which would allow for an already completed interrelation matrix [11]. Of course, this leads to a cut-back on the accuracy of the results but the effort for carrying it out will be reduced as well.

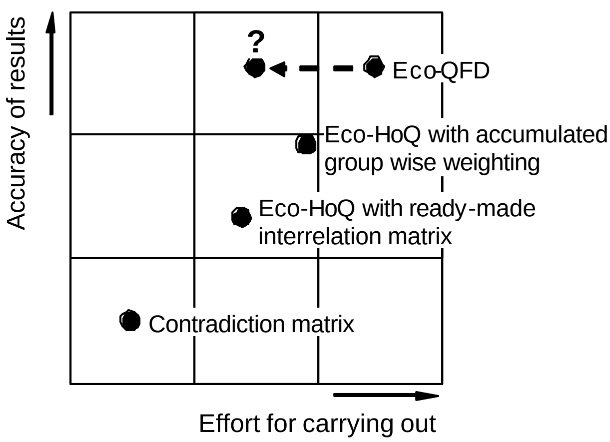


Figure 6. Method-selection portfolio for Eco-QFD

The four possibilities of scaling the Eco-QFDs are also placed in the method-selection matrix (Figure 6). From this figure it can be seen that future development should aim at, e.g., reducing the effort for retrieving results with equal accuracy.

Based on the method-selection portfolio and the paper of Masui, Sakao et al., the idea of an integrated computer-supported approach was born. The Eco-HoQ could be partly automatically derived from the ecological assessment results of ready-made EI'99 scores. The environmental assessment results could be used to automatically fill out the interrelation matrix for the material production, manufacturing and recycling phases. For the use phase the tables and matrices must still be filled out manually.

# 5 Conclusions

## 5.1 Scaling and improvement options

In Figure 7 theoretical scaling possibilities and improvement options are shown and placed in the method-selection portfolio. From the methods and portfolios described above, it can be seen that there are still some blank spots, and therefore, room for scaling and improvement possibilities.

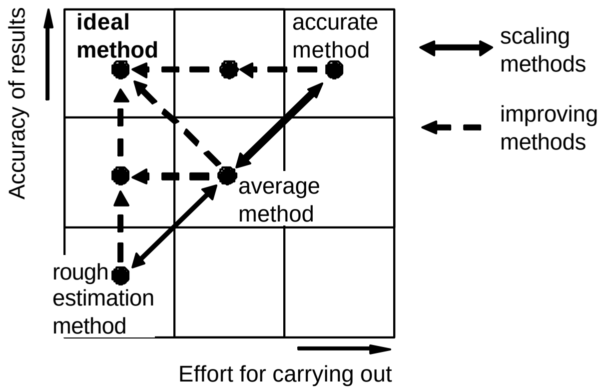


Figure 7. Improvement goal and options by scaled methods

Looking at the method-selection portfolio one might ask why methods are still used which achieve results with a lower accuracy if alternative methods are available which require a similar effort and produce a higher level of accuracy. The answer is simple: Methods with less accurate results usually allow uncertain inputs and, are therefore, more suitable for the beginning of the product development process.

The scaling and improvement options identified from the described examples can be summarized as follows:

- developing different methods for one problem type
- integrating more methods into a single procedure
- condensing the method procedure by omitting steps
- exchanging single method steps within a method
- integrating computer-support for method use
- specializing the method to restricted sub-problems

## 5.2 Method selection

Since methods which achieve more accurate results generally require more effort to carry out, the product developer must find a trade-off between these two criteria. This compromise is influenced by different criteria, whereas the boundary conditions of the problem and the strategic goal, as well as the size of the company, are very important for the method selection.

The boundary conditions of the task consist, among other things, of the availability and uncertainty of data, the identified goal, the problem to be solved, as well as the knowledge and experience of the user. On one hand, an expert, for example, might also achieve good results with a rough estimation whereas a novice might not be able to use a highly sophisticated and more accurate method.

The strategic goal of the company also has a great influence on the selected method since a company which highly ranks environmental aspects needs more accurate results then a company which ranks environmental aspects lower. Smaller companies with fewer resources might be also not able to carry out intensive and accurate methods due to their restrictions. Outsourcing or commissioned work might be a possibility for smaller companies to still achieve the desired accuracy of results. In the end, the selection of the methods is a highly individual decision.

The experience of the Collaborative Research Center 392 shows that scaling the methods before adapting and integrating them increases the chances of successful method implementation. Furthermore, it is in many cases advisable to first carry out a rough estimation to identify the hot spots and then focus on a smaller problem in the detailed analysis.

# 6 Outlook

The scaling and improvement options proposed above are based on experiences made with consumer products and are, therefore, not evaluated for different product categories. In future research, these models and scaled methods must be used on different products. Furthermore, the knowledge gained in scaling methods must be systematically extended to different methods, so that the method-selection portfolio can be modified and extended, resulting in a more detailed model which must then be validated.

The goal of method development should be to first scale the methods over the “diagonal”, so that the product developer is able to choose an appropriate method for his problem. Furthermore, improvement of methods should aim at “breaking out of the diagonal” to achieve a higher accuracy/effort ratio.

Another interesting question is how the methods and the application process differ depending on the novelty of the design. Is it possible to use data from previous methods and cut down the effort when carrying out a variant or adaptive design? Which data can be re-used and which steps can be abridged or omitted?

A procedure for selecting the methods dealing with the problems and choices described above is also an interesting and important field for future researchers to focus on.

As on can see there is still much research left to be done, but this paper is a first approach towards opening a discussion on how to scale and improve methods.

## Acknowledgments

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