AN INFORMATION MODEL TO ESTIMATE EFFORTS OF PRODUCT DEVELOPMENT PROCESSES

Dittmann, Claudia; Jacobs, Georg; Felix, Valerie
RWTH Aachen, Germany

Abstract

Due to small batch series or customer orders with specific requirements, costs and especially development cost are hard to determine. Their impact on the overall costs is enormous and cannot be compensated by current production technologies. To evaluate design efforts, standardized processes are known. Common models as the VDI 2221 are therefore unsuitable due to their generic character of the process steps. They are based on ideal theoretically solutions and do not consider limitations by industrial and organizational constraints. Therefore, a more detailed process is necessary, to make a comparison possible. This paper will show an approach to estimate efforts of a design project as a mathematical function. The process is based on project requirements, the process itself and other related factors which are part of the development. The output is a method for the effort estimation.

Keywords: Effort estimation, Case study, Design process, Complexity, Early design phases

Contact:
Claudia Dittmann
RWTH Aachen
ikt
Germany
dittmann@ikt.rwth-aachen.de

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1 INTRODUCTION

There is a gap between responsibility of engineers for cost and the cost arising in their divisions. In general, it is relatively simple to calculate the total production cost after the engineering design process. However, the design does not only determine about 80 % of the product costs but generate costs due to the design process itself. Regarding Ehrlenspiel et al. it is proven that labour costs exceed the development costs significantly (Ehrlenspiel et al., 2014).
As we can see for small batch series or customer orders with specific requirements, costs and especially development cost are hard to determine in early phases. Their impact on the overall costs is enormous and cannot be compensated by current production technologies. In the past, mass production helped to optimize production processes and reduce the production cost.
The optimisation of development costs already was focus of several papers (e.g. Kessler, 2000). But they are without information about reference values. Without them, there is no comparison possible to give information concerning the success (Griffin, 1993). Estimations needed to have a high dependability to be reliable. Investigations in companies have shown, that there are deviations of proposed time and cost by 1 to 1.5 (Bashir, 2001).
This paper will show an approach to estimate efforts of a design project as a mathematical function. The process is based on project requirements, the process itself and other related aspects which are part of the development process. The output is a method for effort estimation of product development projects in engineering.

2 METHODOLOGY

Numerous models and calculation systems are known to determine costs arising during the product development and his process. The costs which are caused by the development process itself are not or hardly examined and will be topic of this paper.
An information model that clearly outlines the design process and the necessary dependencies offers the possibility to understand the complexity of a design process. Therefore, a terminology based on several working steps, will be introduced. A case study is used to validate the new developed approach and give a first understanding of its feasibility.

2.1 The Standard Design Process

To evaluate design efforts, standardized processes are known. They are generally valid and can be easily adapted to special use cases. This is not a disadvantage, but there is no universally accepted engineering design process. All of them contain several steps which define similar phases. So is does not matter whether we focus on common models as the VDI 2221 (VDI, 1993) or any other description of design processes. They have in common that they are unsuitable due to their generic character of the process steps. They are based on ideal theoretically solutions and do not consider limitations by industrial and organizational constraints (Bender, 2004).
Therefore, a more detailed process is necessary, to make a comparison possible. The disadvantages of this approach are that a high effort for process definition is necessary and the general character is lost (Reich, 2010). New designed products highly depend on general applicability. A definition of process steps cannot fulfil both requirements, being generally applicable and detailed on the other side.
Therefore, the design process is abstracted in a typical model of input - black box - output. The standard process defines requirements and results are outputs like drawings and BOM for the manufacturing of the product. However the steps between those two things are not described in detail and stay blurry for the user. (Ehrlenspiel et al., 2013)
Feldhusen confirms this approach and includes other documents such as necessary test results, 2- or 3-dimensional models etc. but stays vague in its development. (Pahl et al., 2007)
According to Pollmanns the abstraction of the process is based on the following assumptions (Pollmanns et al., 2013):

- Each design process generates similar kinds of documents.
- The type of necessary documents depends on influencing factors like innovativeness. New products result in higher effort due to certification, calculation, etc.

- There is a direct link between the development duration and the generated documents.
- Different kinds of documents require different amounts of time.

This is based on investigations of Hichert and Pauls in the 1970s (Paul, 1976, Hichert, 1976). In order to understand and generate reliable figures about the complexity of a development and a part they proposed to normalize generated document by only using DIN A4 sizes. The number of papers required to deliver all information for production is an objective and comparable figure. Recent development showed that a change is going on concerning the storage of data. More common are paper-free-offices to save money and more important to make a worldwide development and collaboration possible. However, a drawing is still a legally binding document, but is not available as a printed version which makes the generation of a number of documents difficult.
Keeping these problems in mind, design documents are no longer suitable for effort estimations. More important is the generation of information itself and therefore the process must be adapted.
Hence, the adaption of the development process to his tasks respectively to his information is investigated. This concept was involved in the first Information Model which was developed at the RWTH Aachen University. The Information Model and its influencing factors will be explained in detail in Chapter 3. This paper intends to show the current stages of research towards the adaption of the process to the required information.

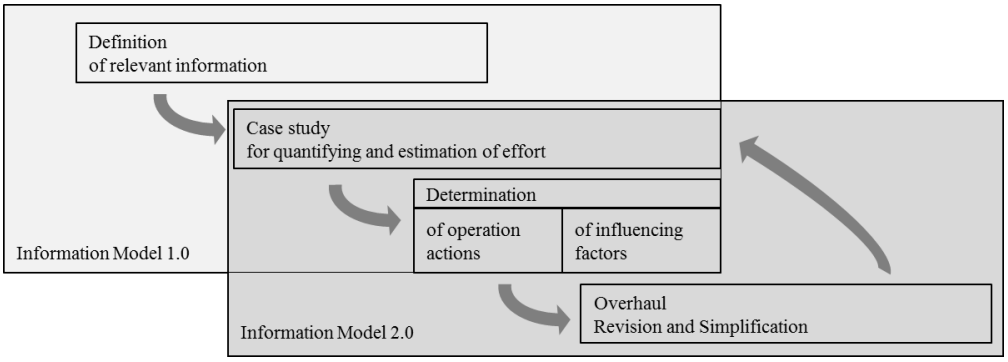

Figure 1. Sequence of working steps

To solve this problem a three-step approach is developed which is shown in Figure 1. The first step is the definition of design relevant information. They needed to be collected and clustered. Within the second step the case study is initiated to quantify and estimate the effort in real term. The third step is the determination of operating actions like handling steps and also the definition of the influencing factors like degree of innovation. Hence the amount of information is analyzed and used as basis for the second Information Model. Reasons for the overhaul and detailed information concerning the models can be found in Chapter 3.

2.2 The Case Study

In general, the adjustment of anything existing is more easy than a new development. Considering 3D-CAD models it is obviously that changing some parameters of an existing model takes less time then developing a new model. Hence, handling steps or so called information operations are defined. A distinction is drawn between the handling options Generation, Processing and Display.
It is called Generation when information needed to be created up to the necessary degree of detail. If information's are repeatedly used, the operation will be counted just once. This information will e.g. change intermediate steps and will be called Processing. Other operations for Processing could be adaption, check or combine given information. The third kind of Operation is to Display. This action is to be considered in addition to the generation e.g. to fulfil legal or customer requirements causing additional effort for presentation.
On basis of an explicated sample construction of a wall holder the connections of the individual work steps are illustrated. The example construction documented all working steps in detail.
The Case Study contains a list with a description of the working steps (details in Chapter 3), the content of the information, the value and which Information Operation had to be applied. The designation of the work steps is divided into Information Cluster and Information.

3 THE INFORMATION MODEL

The basic concept of the information model focuses on the costs per work step of the design process. The individual work steps such as, for example, the valuation with the partial work steps evaluation criteria, weighting, evaluation of criterions and evaluation of results are listed in this information model. Each work step is associated with an Information Operation. Based on literature enquiries process information were collected from several different fields (Frankenberger, 1998). Single information were taken into account and collected.

3.1 Version 1.0

"Presumptive documents" were clustered for clearer arrangements eventhough these documents may never be required during design process. "For a specific process, information could be clustered to different groups resulting in completely different documents" (Pollmanns et al., 2013). They are kept as tacit knowledge to be at hand if necessary. Table 1 is showing a list of the first sorted results.

Table 1. Example of Information Cluster and its Information (excerpt)

	Case Study		Changing by Innovation		
	Information Operation	Additional Display	Information Operation	Additional Display	Amount
Evaluation					
assessment criteria	Processing		Generation	Display	
Loading	Processing		Generation	Display	
Evaluation of criteria	Generation				
Result of evaluation	Processing	Display	Generation		
Notes	Generation	Display			++

The next step was the graphical presentation as seen in Figure 2. Due to the size of the Information Model only an excerpt will be shown here. Here you get an idea of the interrelationship between the information cluster (dotted line) and their corresponding information. In total 29 categories with 98 sub-classes create the Information Model. Requirements, wishes etc. represent the process input and the purpose of the new product.

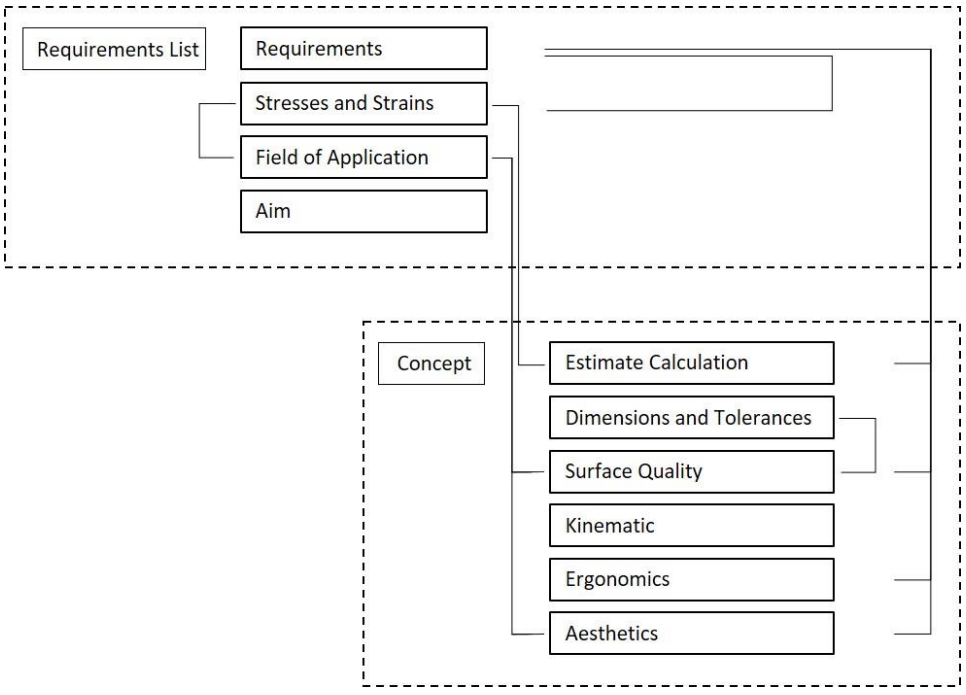

Figure 2. Excerpt of Information Model 1.0 (Pollmanns et al., 2013)

Another content of Information Model 1.0 are Influencing Factors. They have impact on all Information Clusters and their content. They were also analyzed in the very beginning and nine factors are determined.

Table 2. Influencing factors and their Definition (according to Pollmanns 2014)

Factor	Description	Possible characteristics
Novelty	Type of construction	New construction Adapter construction Construction of variation
Innovation	Comparison to state of the art	$0 < X \leq 2$
Cross-linked of parameters	Subjective assessment of dependency for performance parameters	Low High
Product size	Number of levels of functions in comparison to other products in company	≤ 1 (normed)
Difficulty of the design task	Assignment of probability of appearance and estimated weightiness of impact	1 - 20 or 1 - 1000 by using FMEA (failure mode and effect analysis)
Employee experience	Combination of project-specific know-how and experience concerning the company	Low Medium High
Team aspects and working environment	Combination of existence of interdisciplinary teams and management by motivation	1 - 6
Multi-site development and development outsourcing	Number of interfaces between R&D division (also subcontractor and international location)	Low Medium High
Process Definition	Existence and comply on predefined development processes	Yes No

The factor Innovation describes the product`s novelty and product size describing the complexity. Both will be explained in detail now.

A deviation of standard requirements concerning innovation has a huge influence on the development costs (Heller et al., 2012) and on the new product. Its deviation from previous generation leads to an increase of the cycle time. The factor differs between the characteristics new for the company, new for the market and no innovation. The company must put effort into the development if it is a real new product. When competitors already have developed a similar product, which is available, then an analogy or benchmark is possible. Hence, there is an impact onto the company´s effort as development cost and cycle time influence the product development.

For physical products, it is proven e.g. by Griffin (Griffin, 1997) that the actual product size has an impact on the development and its needed effort. In the very beginning, there is no estimation by the number of parts possible. Therefor the number of functions the new product has to fulfil are defined (Bahir et al., 2001).

Reasons for the iteration of Information Model 1.0 were e.g. a lack of consistent process flow. Information seems to be not clearly connected. Not all information are linked to other tasks or information. Some logical connections are missing like specification to function structure. The question is if there are technically relevant information which have no input or output or if connections are missing in general.

Additional to the mentioned points before, the table of process information and their influencing factors span a matrix of 25x107. This is to laborious and its prone character create the possibility of mistakes by operator. Other challenges concerning Information Model 1.0 are the proposed determination of Influencing Factors seen in Table 1. Hence, the question arises: How to use this Information Model or its information for an easy use by being less vulnerable.

3.2 Version 2.0

The information of Information Model 1.0, that abstracts the design process to the information assimilation, is evaluated for Information Model 2.0. The focus in Information Model 2.0 is on the dependencies of the individual steps to the design process. Generally, it is necessary to complete one work step before starting with a depending step. The connection leads to a sequence that influences the total effort and links to the calculable conclusion that considers the dependencies.
The information model 2.0 provides a matrix which reveals the individual production steps listed in Information Cluster and their Information.

Table 3. Excerpt of Matrix

		Evaluation	assessment criteria	Loading	Evaluation of criteria	Result of evaluation	Notes
Evaluation			0	0	1	1	0
	assessment criteria			0	1	1	0
	Loading				1	1	0
	Evaluation of criteria					1	0
	Result of evaluation						0
Notes							

There is no distinction between a forward- or back-directed-connection of the information flow. The dependency of the Information Cluster is characterized by a cross in the respective interface in the matrix. The analysis of the underlying information sources leads to an alignment of the Information Cluster and Information and at some place to a deletion. Therefore, the listing in the matrix is analogously to the design process as shown in Table 3. The dependencies from the example construction and from further considerations while a modification of the design task takes place, as well as the connections of Information Cluster in the graphical information model, provide the necessary iterations in a construction process and are pictured in the matrix.

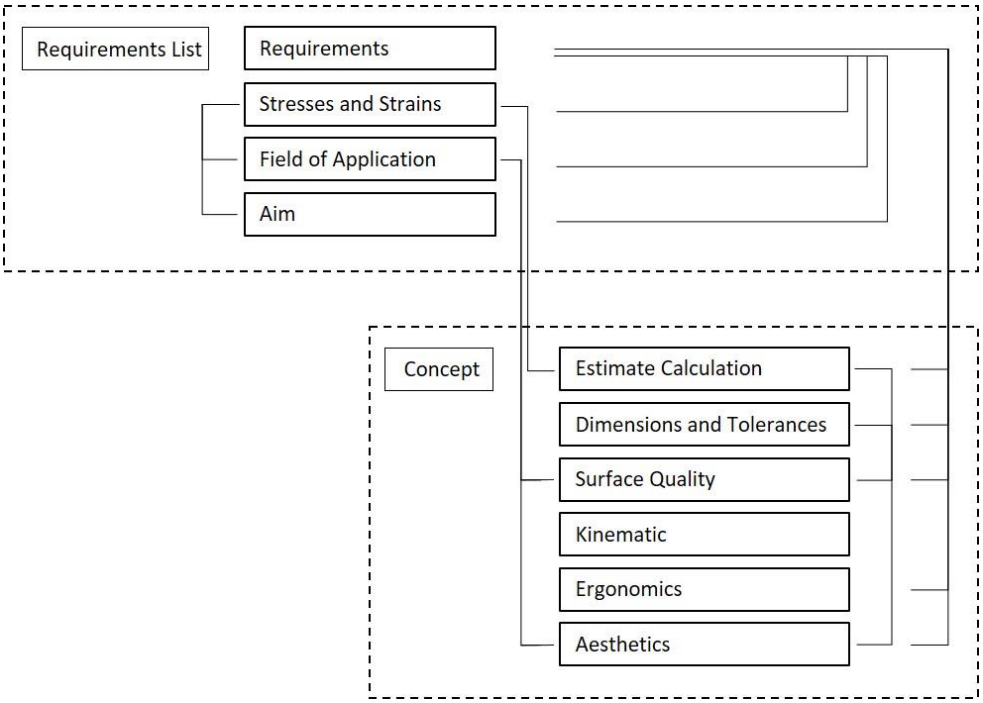

Figure 3. Information Model 2.0

Figure 3 is showing the result of the overhauled Information Cluster again for the phases Requirements and Concept and its interrelation. Both belongs to the category Preparatory Work.
The Information Clusters are assigned to the four categories Preparatory Work, Design & Construction, Planning & Post-Processing and Documentation. This is already a preparation for later research for more simplification, details in Chapter 4.

4 REFLECTION ON MODELL: RELIABILITY AND VALIDITY

The dependency matrix establishes the possibility to trace the information flow during the design process. In this way, it is possible to understand where the necessary information for a partial work step comes from and consequently the necessary preparation for this work step can be recognized.
In addition to that, the relative proportions of the individual design steps in the matrix can be calculated thus it is possible to recognize the synergy effects of the work steps. The amount of work can be reduced if the work steps obey one another in such a way that the succession depends mainly on the dependencies. Using the matrix, the effort can be calculated considering the dependencies of the individual production steps. For a specific calculation, it is necessary to accumulate more experiences and compare the carried-out design processes with the information model including the determined effort from the information model with the handling variants.
Due to the representation and subdivision in Information Cluster and the four categories, also conclusions about the dependencies within an Information cluster or the Information can be drawn. On basis of the dependencies shown in the development process, time-critical design steps can be identified.
It is conscious that a verification of the method is urgent. First analyses with a company had shown several difficulties concerning collaboration. We gain insight little projects which besides had a lack of patency of data. On these grounds, we focused so far on theoretical aspects and are looking forward for a business case to verify the method.

5 DISCUSSION AND CONCLUSION

The assessment basis is created by a first assignment of the Information Operation, and subsequently, between nine influencing aspects. Each factor however, needs to be reviewed regarding its dependencies onto each other. They relate to the factors of influence for the design of a product and the environmental factors. Within the single criteria, the novelty, innovation, networking, size, criticality, experience, team aspects, distributed locations and process definition are considered. The dependencies among the individual work steps which may lead to a time delay and therefore to an increased effort are not considered here.
A model that has no quantifiable values cannot make a statement about the costs. To be able to evaluate the determined values additional construction tasks must be carried out in the company. By a comparison of the values, however, the costs are still not quantifiable.
Other tasks which are following soon are the correlation of the design process to the Influencing Factors. This will help to simplify the model and make an easier use possible. Therefore, a Decision support system is planned to be used as a Management tool.

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