Enabling Cost Efficient Product Design – An Interview Study on Relevant Manufacturing and Cost Information in Early Phases of Product Development

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Abstract: For the development of successful products, the product costs are a crucial factor. A great influence on the product costs can be made within early phases of product development. Needs regarding manufacturing and cost information as well as their influence on cost efficient design decisions have to be understood. To gain this understanding, a study including a six-month observation in a corporate research organization of a large German enterprise and seventeen semi-structured interviews in three enterprises were carried out. The research design was guided by three research hypotheses.

First, this study shows different needs regarding manufacturing and cost information for different roles. Nevertheless, the differences are not always clear between roles. Second, it was recognized that there are cost relevant and irrelevant projects. Within the cost relevant projects, the provision of manufacturing and cost information is seen as beneficial. Also decision making for complex products is described as a team process with different knowledge domains required. Third, benefits are seen in information reuse and knowledge transfer from similar products. Participants mentioned a need for support with finding and using manufacturing and cost information.

With its results, this interview study has extended the area, in which the model of PGE and with it reference system elements are seen to add value to design to cost within corporate research. This study therefore enables design method development for manufacturing and cost information. Finally, the findings of this study enable new technologies to find their way into corporate practice. As many new technologies have difficulties taking a share in mass production, the availability of cost and manufacturing information is essential.

Keywords: Design Research, Interview Study, Design to Cost, R&D Management

Introduction

Current product development faces major challenges. Among them, complexity leads to difficulties for development teams to fulfil the required functions (Matthiessen 2011) as well as optimized costs and manufacturability (Horsch 2018). One complexity driver is the shift from mechanical products to complex mechatronic systems (Belhoff et al. 2014), another are new manufacturing processes. In additive manufacturing for example, various technologies are emerging (Gardan 2016). A third complexity driver is the increasing amount of variants through mass customization leading to a need for automated, but accurate cost estimation (Tu et al. 2007).

Another major challenge for product development is cost pressure (Ehrlenspiel et al. 2003). Especially in an era of disruption, design to cost plays an important role to secure profitability. An efficient cross-domain reuse of manufacturing and cost information is needed. Different methods and models within scientific research can therefore be used. For the efficient adaption and development corporate practice needs to be understood better. This study aims at identifying relevant manufacturing and cost information as a first step to the development of support methods.

Cost management for product development

Frankenberger (1997) defines cost management as targeted and systematic control of costs. The objective is influencing the product costs, processes and resources through concrete measures to sustainably improve competitiveness (Frankenberger 1997). Within product development, Ehrlenspiel et al. (2007) name three fundamental claims: Developing market-driven products, developing cost-driven products and realizing cost efficient product development processes. The need for cost management within product development is generated as approximately 70 percent of costs are set within development and design, while only around nine percent of the total costs are realized in the same timeframe (VDI2235).

From the scientific beginnings in the 1980s onwards, cost management for product development has become important (Ehrlenspiel et al. 2020). Especially large enterprises have established methods, tools and organizational units to support the development of manufacturing and cost optimized products. The specialized cost engineering role has therefore been established. According to VDI2800 design to cost is a "Method of project management, which makes it possible to control a project from start to finish in such a way that a certain performance is achieved within pre-specified cost and time targets." (VDI2800). Design to cost includes the disciplines of cost estimation, value engineering, cost control and quality design (Michaels and Wood 1989). This leads to a transparency gain and the identification of cost leavers.

Modern product design requires profound knowledge from different domains. For complex products, this can only be done by well-assembled teams (Guerineau et al. 2018). As those teams require different roles, the first research hypothesis is derived:

> **RH1. Different roles need different manufacturing and cost information**.

Clarification of manufacturing and cost information

Design decisions have a strong influence on product costs (Frankenberger 1997). Cost efficient design decisions lead to lower product costs. One influence factor is the competence of the decision maker, a second is the fast availability of information about the alternating design variants (Frankenberger 1997). While increased information availability is beneficial for product costs in general, this study questions the availability of manufacturing and cost information within corporate research, where most projects include high risk and low structure. Therefore, they can be considered as being in an early project phase (Verworn 2005).

Elements from the model of PGE can be used to lower risks and development effort (Albers et al. 2017). To get further implications about the specific information needed in cost management for product development, the second research hypothesis was developed:

> **RH2. The provision of manufacturing and cost information leads to cost efficient design decisions.**

PGE – product generation engineering

According to Albers et al. (2017): "Most products are developed in generations". Therefore the model of PGE is introduced. New products can be classified by the share of newly developed and carried over subsystems for reduction of risks and costs (Albers et al 2014). From those, specific reference system elements (RSE) can be carried over or varied (Albers et al. 2019). All reference system elements add up to the reference system (Albers et al. 2019). Reference system elements can come e.g. from predecessors, competitive products, R&D projects or university research (Richter et al. 2019). This study investigates the transferability of methods and elements of product generation engineering on the case of manufacturing and cost information. Therefore, the third hypothesis is presented:

> **RH3. Manufacturing and cost information from a reference system can support the development of future products.**

While the added value of product generation engineering is proven for product design (Albers et al 2014), the usability within design to cost is questioned within this study. Especially the situation, relations and needs within companies need better understanding. Also Mörtl and Schmied (2015) find corporate practice as the most important source for research in cost efficient design.

Methods

Study design

The research project aims on a better understanding of information use within design to cost. Therefore, three research hypotheses were derived in the introduction. The research is based on the Design Research Methodology (DRM) (Blessing and Chakrabarti 2009). The study includes the steps of a comprehensive descriptive study I shown in Figure 1. The first step reviewing the literature includes identifying the existing understanding through literature (chapter 1). In the second step, factors and links of interest are being identified and extended and based on that, the research questions and/or hypotheses formulated (chapter 1). The third step includes the selection of research methods and e.g. the development of questionnaires (chapter 2). Within the fourth step, the empirical data is being collected, analyzed and results being discussed (chapter 3). The last step includes an overall conclusion as well as suggestions e.g. for support and future work (chapter 4).

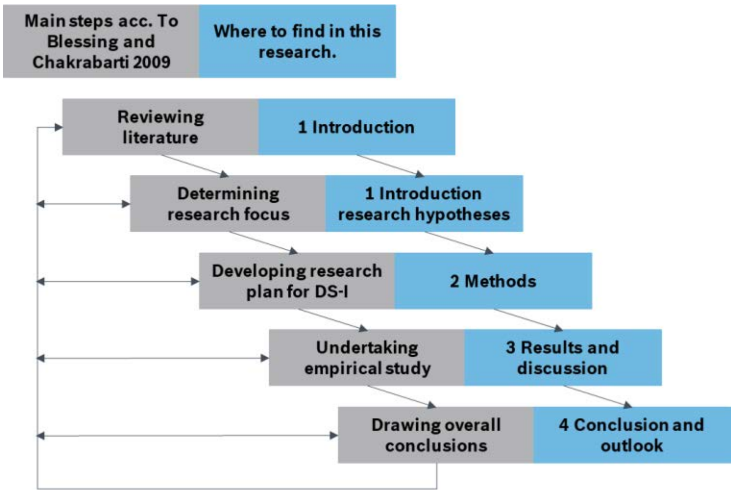

Figure 1: Main steps in a comprehensive descriptive study I (left) (Blessing and Chakrabarti 2009) and where to find them in this paper (right)

The interview guide is based on a literature review and a six-month observation of design to cost activities in corporate research at a company site of a German enterprise with different product fields. Five pre-interviews were carried out for validation of the interview guide on participants not interviewed later in the original study. Table 1 shows information on them.

Table 1: Participants information (pre-interviews)

#	Role	Relevant experience	Product focus
Pre1	Cost Engineer	> 10 years	Electronics
Pre2	Cost Engineer	> 10 years	Sheet metal
Pre3	Cost Engineer	5 - 10 years	Healthcare
Pre4	Design Engineer	> 10 years	Gears
Pre5	Group Leader	5 - 10 years	unspecific

Interviews

The conducted interviews were semi-structured interviews, combining a part lead by an interview guide including open and closed interview questions. The interview guide allows a broad coverage and gives enough flexibility and openness towards the study outcome, but also contains questions and answers determined in advance. It therewith eases the analysis and can provide qualified information (Blessing and Chakrabarti 2009). Various researchers used interview studies with semi-structured interviews to analyze needs and challenges of engineers in corporate practice (Doellken et al. 2020, Schweigert-Recksiek et al. 2018, Beckmann et al. 2014).

The participants are working within three large sized companies with over 10.000 employees, as those are in the focus of this study. Moreover, the chosen companies have a large manufacturing know-how regarding diverse products with similar elements. Table 2 shows a detailed overview of the participants.

Table 2: Participant and company information

#	Role	Relevant experience	Product focus
Int1	Design Engineer	1 - 5 years	Fuel cell
Int2	Design Engineer	> 10 years	Electric machines
Int3	Design Engineer	> 10 years	Healthcare
Int4	Design Engineer	> 10 years	Turbo machines
Int5	Design Engineer	> 10 years	Electric machines
Int6	Design Engineer	> 10 years	Turbo machines
Int7	Design Engineer	> 10 years	Electronics
Int8	Design Engineer	> 10 years	Fuel cell
Int9	Product Management	1 - 5 years	Trains
Int10	Cost Engineer	1 -5 years	Turbo machines
Int11	Project Leader	5 - 10 years	Electric machines
Int12	Design Engineer	1 - 5 years	Truck powertrain
Int13	Cost Engineer	1 - 5 years	Electronics
Int14	Project Leader	1 - 5 years	Healthcare
Int15	Research Engineer	1 - 5 years	Gears
Int16	Research Engineer	5 - 10 years	Gears
Int17	Cost Engineer	5 - 10 years	Electric machines

The participants have a relevant job experience between one and thirty years with seven over ten years (Figure 2). This is beneficial, as the average age of employees within mechanical engineering industry in Baden-Württemberg is over forty years and therefore the average job experience can be estimated above ten years (Pristl and Käpplinger 2013). Other studies (Christiaans et al. 2005, Gladysz and Albers 2018) focus on less experienced candidates or students. This study therefore strives for an improvement in transferability to corporate research by interviewing experienced participants.

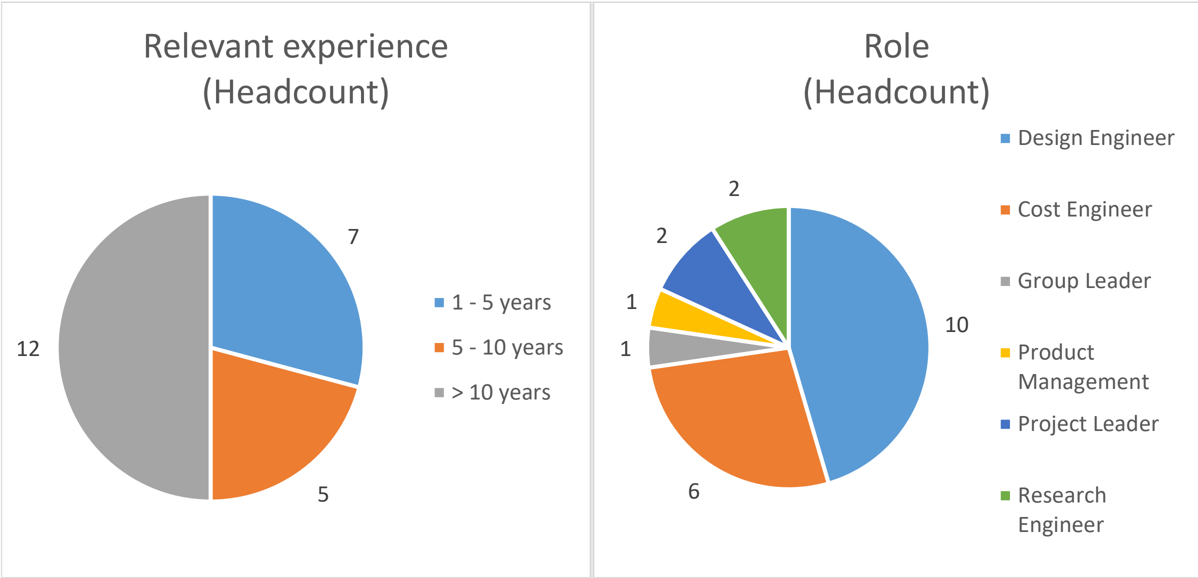

Figure 2: Relevant experience (left) and role of participants (right), both including pre-interviews

There are two focus roles. First design engineers, because of their important role in the design process. Second cost engineers, as their job is to include the manufacturing and cost perspective into early phases of the design process. For transferability of the results, participants with different product focus were chosen (Figure 3).

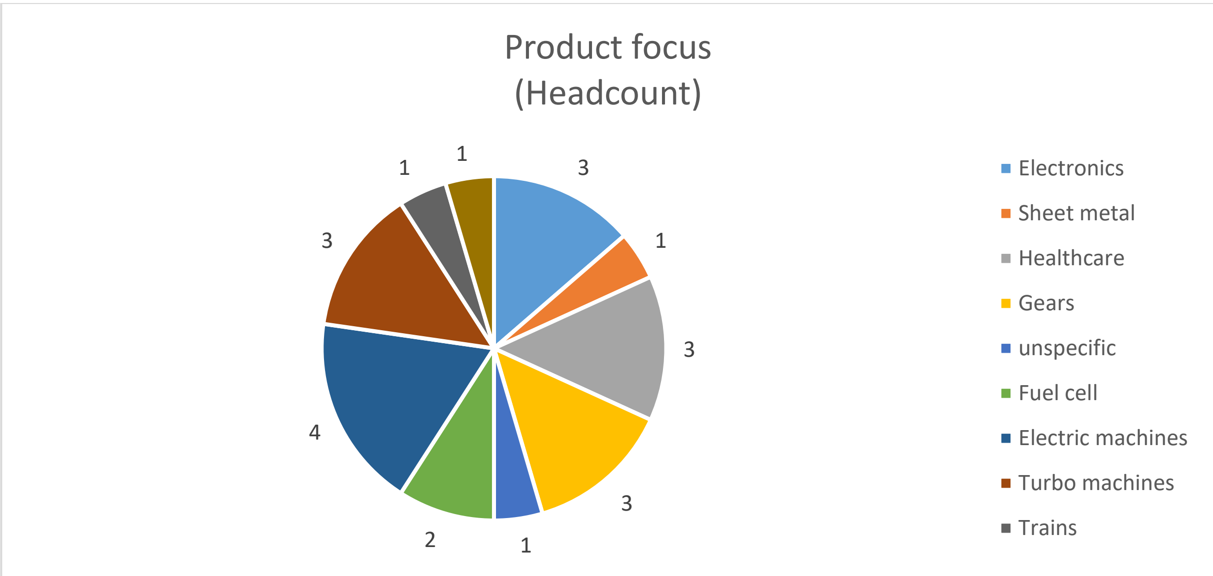

Figure 3: Product focus of participants including pre-interviews. With only one product focus per candidate.

All interviews lasted between 45 and 70 minutes. After a short introduction on the research topic by the interviewer, the interviews started with questions about demographic data. Due to corporate security reasons, there was no audio recording. All interviews were protocolled with explicit recordings of relevant cites.

Analysis

To get qualified results, a cluster analysis according to Blessing and Chakrabarti (2009) was done based on the digital protocols. Therefore, similar answers by meaning were grouped. For example, the answers to the question how the product costs impact the participants were clustered into the two categories very strong/strong impact and weak/no impact. As there were open questions within the interview guide, there were clusters of answers and comments connected to the questions. For example, eight participants claimed besides their answer on the impact of product costs on their work results an influence of the project type. When such a cluster was detected within the interviews, a new category was created. After all, the questions and answers were grouped to the corresponding research hypotheses.

Results and discussion

Different needs (RH1)

Different roles need different manufacturing and cost information.

To analyze different needs among roles, the candidates were asked about the influence of product costs on their work and the influence of their work on product costs. All cost engineers and project leaders mentioned a strong influence of product costs on their work, even though two of them described that the impact depends on the project (Int10, Int14). On the same topic, both research engineers do not see an influence of product costs on their work but mentioned a major influence on product costs through their work (Int15, Int16).

To gain a better differentiation, the participants were asked about the influence of the availability of cost information and manufacturing information in separated questions. All cost engineers and project leaders answered with a strong or medium influence of the availability of cost information on their work results. Whereas only four out of nine design engineers recognized the same (Int2, Int4, Int5, Int6). Underlining this result, one design engineer added that in the first step, costs are not relevant, because the function is in focus. Only after functional validation, costs come into play (Int5). On the same topic, both research engineers saw no or minimal influence of the availability of cost information on their work results. About the influence of manufacturing information on the work results, there is a more similar understanding. Only research engineers see small or no influence, whereas for all others there is a common agreement on the influence.

On the question what cost information a strong influence on their work results has, the participants gave diverse answers. Among others, they mentioned material costs, concept costs, target costs, overhead costs, surcharges, quantity, sensitivity analysis of cost models, cost models, cost drivers on process level, transfer prices and comparative prices. The open question, what kind of manufacturing information has a strong influence on their work results, was answered diversely as well, even though some of the answers fit into the same categories. The most common categories are shown in Figure 4. Tolerances and manufacturability were mentioned the most often, process details and material are following.

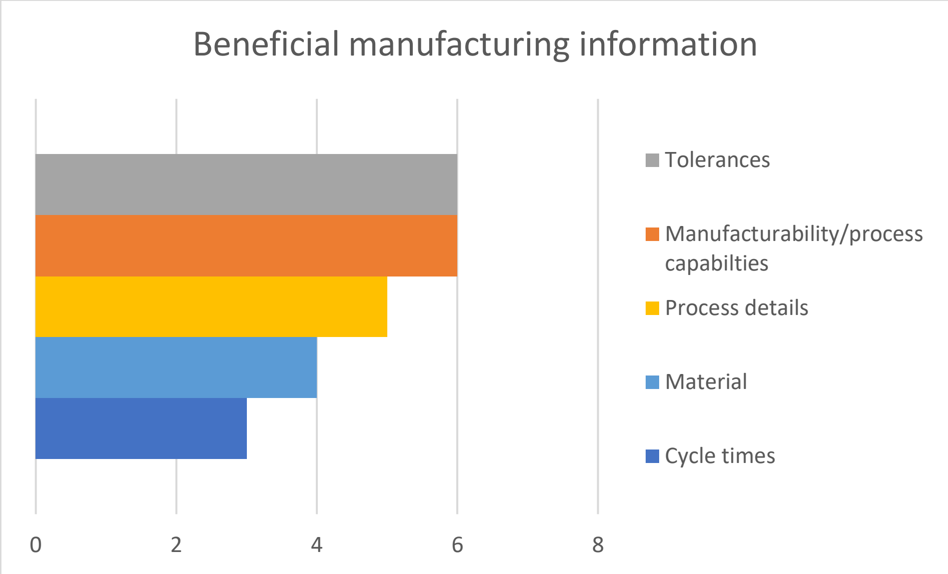

Figure 4: Mostly named beneficial manufacturing information

Discussion:

This section shows that the interviewed candidates see different manufacturing and cost information as influential on their work results. This leads to different needs of information for different roles and therewith supports RH1. Nevertheless, the differences are not always clear between roles. Other factors as well have an impact. To identify these factors, a more detailed study needs to be carried out. From the interviews as well as the observation there are indications that among others the product focus and relevant job experience are relevant.

Especially for evolving technologies, it is important to have access to manufacturing and cost information. When the general level of knowledge about a technology in a company is low, information on future product costs is valuable.

Cost relevant projects (RH2)

The provision of manufacturing and cost information leads to cost efficient design decisions.

Fifteen out of seventeen participants stated that the availability of manufacturing information has a medium or high influence on their work results and ten out of seventeen mention the same for cost information. Building on that, increasing the availability through the provision of manufacturing and cost information should lead to better work results. Contradictory, different participants added concerns about additional information provision, due to an already existing overload of information (Int3, Int5, Int6). Even more the difficult part for some was sorting out not required information (Int3, Int5). Others showed a need for a better information transfer regarding manufacturing and cost information (Int4, Int9, Int10, Int13), as nowadays most of the knowledge domain is the personal network (Int2, Int4, Int8). Explicitly, different candidates wished a better knowledge flow from series manufacturing to corporate research (Int2, Int4, Int10).

Regarding the influence of product costs on the work of the participants, thirteen mentioned a strong influence, whereas eight mentioned a small or no influence. Three participants mentioned both categories (Int5, Int7, Int8). Additionally, different candidates stated that it depends on the project, whether product costs influence their work or not (Int3, Int5, Int7, Int8, Int9, Int10, Int12, Int14). A design engineer added it depends as well on personal initiative, because it is not asked, but beneficial for later transfer in series development (Int8). Within the study, it was observed that cost engineers are only working in projects, when product costs were considered highly relevant by project management. This explains why all cost engineers within this study mentioned a strong influence of product costs.

Discussion:

On the question how their work influences product costs, fourteen participants mentioned that it takes place as part of a development team. One cost engineer supports this as he stated, especially for complex products, decisions cannot be made by one person without the knowledge from the different domains (Int5). Keeping this in mind, the provision of manufacturing and cost information by itself does not directly lead to cost optimized designs. For complex product development the creative process of interaction is needed. The interaction within and composition of development teams therefore are factors of influence.

Summarizing, there are participants seeing a strong influence, while others or even the same seeing medium or no influence. Therefore, the findings do not support a verification or falsification of RH2. Further research and detailing of RH2 is needed. However, there are cost relevant projects where the provision of manufacturing and cost information is important and others where costs have small or no influence and therefore the provision of manufacturing and cost information brings no benefit.

Support based on previous products (RH3)

Manufacturing and cost information from a reference system can support the development of future products.

On the question how their work is guided by existing products, thirteen participants stated that guidance through existing products is important, including all cost engineers, project leaders and seven out of nine design engineers. Even though the majority saw an importance in using information of existing products, eight candidates have problems finding fitting reference system elements (Int1, Int5, Int6, Int8, Int11, Int14, Int15, Int16). Whether the problem was a lack of existence, the lack of well-fitting or a problem of finding reference system elements, was not considered within this study. But as observed within the observation and stated by different participants, there is no suitable knowledge management system for manufacturing and cost information (Int10), nor an established information reuse support (Int13). Additionally, participants mentioned problems with manufacturing and cost information transfer from series production back to corporate research (Int2, Int10). Known barriers are compliance issues and concerns by suppliers and internal manufacturing locations not wanting their cost information spread (Int10).

To further understand the needs, five relevant examples of manufacturing and cost information were identified within the pre-study and then used for a question in the main study. Figure 5 shows the answers on the question how different information of similar products would influence their work results on the product in development. Information on the process chain and detailed process information is rated as most beneficial, with eleven and nine out of seventeen candidates thinking about those as very helpful or helpful. Participants identified the transferability of that information as challenge. It was added that for absolute component costs the transferability is an individual decision and quantities, location and other additional information is needed for classification.

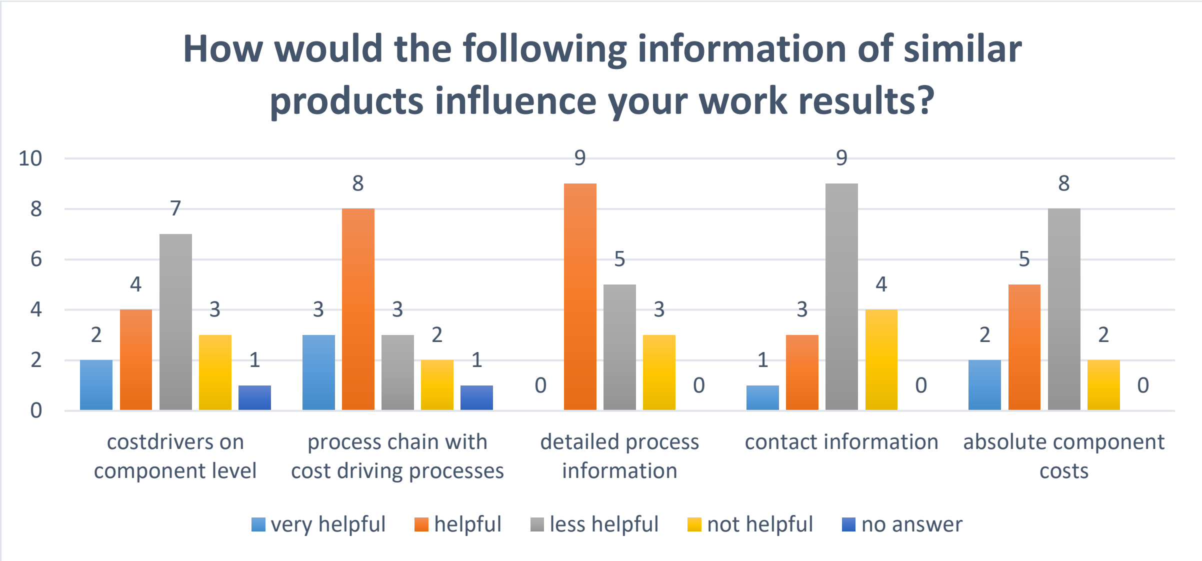

Figure 5: Answers on the question how the following information of similar products would influence their work results

Participants reported that a special property of cost information is its need for background information (Int8, Int10). One cost engineer stated that cost information without explaining information is useless (Int10). For example, detailed absolute manufacturing costs without information on the location, overhead rates or documented reasons for strategic decisions are not reliable, as the influence of the manufacturing process can be less than the influence of location-related wages.

Discussion:

Summarizing the previous explanation, a support for the reuse of knowledge based on existing manufacturing and cost information is seen beneficial. Moreover, in consent with the model of PGE it was stated by participants, that it is more difficult to make a transition from a product outside the company or from a different business unit, than from products within the same department (Int2, Int10). One named reason is a harder reach of knowledge (Int10). Additionally, it was observed within the study that the possibilities of reaching knowledge and information to similar products outside the department was strongly dependent on the personal network. A design engineer stated that he reaches information, others would not receive easily, through personal contact to a production site he earlier worked at (Int2). Another candidate explained that they search for similar existing cost information by writing an email to colleagues, asking if someone has worked on a similar topic (Int13). As both examples were no restricted information these examples show that the information flow can be improved.

As the number of variants is growing due to product customization, automation and digitalization can support product development. With a growing number of manufacturing technologies, knowledge management gets more important, as the product development team needs an easy access to relevant knowledge. Within product development, established technologies are often preferred over new technologies due to development risks. To enable emerging technologies, an improved knowledge transfer can help to reduce development risks.

Overall, the findings within this study support RH3. Benefits are seen in information reuse and knowledge transfer from similar product development activities. However, a need for better support with information reuse and knowledge transfer is seen. Recognizing the importance of cost-efficient design in early design phases, improvements in connection with the reference system can realize a reduction of development effort through higher carryover variation shares as well as improved product costs.

Conclusion and outlook

This study examined the status of design to cost within corporate research. Best practices and needs regarding manufacturing and cost information and challenges regarding knowledge management were identified. A six-month observation as well as seventeen interviews were carried out. The research design was guided by three research hypotheses that led to the following summarized findings:

First, the participants evaluate different categories of manufacturing and cost information differently in the impact on their work regarding their role. This supports RH1, even though differences are not only observed between roles.

Second, the findings within this study do not support RH2 in general. It was recognized that there are cost relevant and irrelevant projects. Within the cost relevant projects, the provision of relevant manufacturing and cost information is seen as beneficial. It was added by most interviewees that decision making for complex products is a team process, as different knowledge domains are required. As this study cannot verify or falsify RH2, this is a task for future research.

Third, within this study benefits are seen in information reuse and knowledge transfer from similar products, what supports RH3. Nevertheless, participants mentioned a need for support with finding and using valuable reference system elements in the field of manufacturing and cost information.

With these findings, this interview study has extended the area, in which the model of PGE and with it reference system elements are seen to add value to design to cost within corporate research. As design to cost is mainly driven by practical need, it is important to understand challenges, needs and interaction of roles. This research therefore enables future scientific research and design method development dealing with manufacturing and cost information. Continuing this research based on product generation engineering allows to profit from already existing models and methods.

Moreover, the present findings are aiming at enabling new technologies to find their way into corporate practice. As many new technologies have difficulties to take a share in mass production, the availability of cost information and manufacturing knowledge is essential for their success. Mass customization and with it an increasing number of variants in combination with new technologies lead to growing complexity. This underlines the need for automation and digitalization in the field of manufacturing and cost information processing and knowledge management.

Finally, the presented study took mainly place in corporate research of large companies. Further research is needed to apply the findings on product development in general. Also further research on support development for manufacturing and cost information is planned to improve accessibility based on the reference system. This has potential to realize a reduction of development effort through higher carryover variation shares as well as improved product costs.

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