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Challenges in product variant costing – a case study

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Abstract

This study explores challenges in decision-making for product design due to insufficient cost transparency because of product variety across the value chain. Utilizing a literature review and a case study on a company, it delves into issues such as value chain consideration, product family assessment, linking effects to specific product levels, and converting measured effects. Highlighting the critical need to address these challenges for decision-making. Future research should focus on a comprehensive costing framework, explore effect interdependencies, and expand the value chain analysis.

Keywords: decision making, design knowledge, variant management, variant costing

1. Introduction

Manufacturers are obliged to develop diverse product portfolios to meet market demands, appeal to different consumer segments, and differentiate themselves from competitors. They may also customize or create unique versions when it is advantageous. Product offerings evolve with component innovations and are influenced by market trends (Kwapisz et al., 2019).

To elaborate, the rise in product variety is driven by factors such as customer demand for new features, customizations, regional requirements, diverse market segments, and certification requirements. New materials and technologies enable unique product features. Furthermore, the competition between manufacturers to capture larger market shares by distinguishing their products is another substantial driver for increasing product variety. The concept of variety can be applied to products and services, where providers aim to enhance economic benefits and consumer value by offering a broader range of choices, unique features, customization options, and personalization (ElMaraghy *et al.*, 2013). Managing a company's product design variability can affect efficiency, production lead times, and order fulfilment. Process complexity will increase in correlation with the growth in internal product variance and can potentially diminish any benefits gained on the market from the extension of the external product variety offered (Hvam et al., 2020; Kwapisz et al., 2019). Leaving a notable incentive to be able to reduce the internal variety of the products without reducing the external variety in the product portfolio offerings.

A major part of product variance is generated through design decisions. Estimates indicate that these decisions account for over 70% of a product's life cycle costs, a greater focus should be diverted towards creating transparency of the costs related to each value chain step (Fadeyi and Monplaisir, 2022). Thus, providing design engineers with the necessary knowledge that would evidently improve decision-making (Windheim et al., 2016). Considering overhead costs alongside direct costs will lead to different product design decisions during concept development by supporting designers with effort-reducing cost prognosis (Ripperda and Krause, 2017). However, this tends to be a complex and resource-intensive process, which we will investigate further.

This paper reviews the literature to uncover the effects and challenges of having a lack of cost transparency throughout the product value chain for design decisions, following an industry case study on a manufacturer of compaction machinery for large-scale waste recycling. Thereby illuminating the challenges of providing design engineers with sufficient knowledge for design decisions. The results of the case study are held up against the current literature to identify existing gaps in knowledge and methods, indicating why design engineers base final design solutions on only a limited amount of information and finally providing an outlook on what challenges need to be met to improve the effects of design solutions on the overall value chain.

2. Research methodology

A literature study was conducted to identify possible challenges to further investigate in a case study. The literature study took its outset in work conducted by Hvam et al. (2020), Ripperda and Krause (2017), and Greve et al. (2022) and from there worked backward through the related literature. The challenges found in the literature were then reviewed and compared to the challenges found in the case company and are discussed further in section 6.

The case study described in this paper is on a company that designs and manufactures compaction machinery for large-scale waste handling. It is a relatively new market with few competitors, and the company is amongst the top enterprises on the market currently. The waste varies from EPS (Expanded Polystyrene) to aluminium, to food waste, and even cosmetics and paint can be handled by their products. All these different purposes set different requirements for the products and thereby the business processes. The company's business processes range from engineer-to-order to make-to-stock.

To understand the challenges found in the literature, the critical activities in the order- and data flow between departments in the organization have been mapped starting with initial activities in the value chain and progressing gradually from one phase to the next starting with sales. Data has been collected over a period of 12 months and has included the researchers as observers. A complete screening of the company data sources has been made to give the best background for the analysis to ensure proper coverage of the challenges faced by the company regarding product variance and include technical product data like the bill of materials (BOM), CAD (Computer Aided Design) models, sales data, and economic data (cost, revenue, etc.). Semi-structured interviews have also been conducted with managers and employees in all functions related to product variety to map the activities and data flow in the products' value chain. In these interviews, challenges regarding operations or IT (Information Technology) infrastructure faced by the company in general or specific individuals came to light and were discussed further. Detailed notes of statements and process flowcharts were used to document the interview outcomes. Furthermore, the authors of this paper were granted access to the company's facilities and IT systems and have made first-person observations of challenges in the systems and operations of the company. The conclusions presented here have been validated by the case company.

3. Literature review

This literature review aims to give an overview of current research within the field of decision-making, support in early-stage design phases, and identify already known challenges in the literature.

The effects of product variety have been widely investigated in past research, and there is a general consensus in the literature that an increased level of internal product variety will induce higher levels of cost (Israelsen and Jørgensen, 2011; Ripperda and Krause, 2017). Thus, a large number of methods and tools have been developed to gain control over the natural increase of product variance within a product architecture over time, such as the concepts of Product platforms, module based product architectures, mass customization, and commonality (Boas *et al.*, 2013; Cameron *et al.*, 2017; Gauss *et al.*, 2021; Jiao *et al.*, 2007; Kwapisz *et al.*, 2019; Meyer and Lehnerd, 1997; Otto *et al.*, 2016; Tseng *et al.*, 2017) as a mean to reduce a growing problem. However, the constant need for developing, customizing, and optimizing products significantly enlarges part variety. Making it increasingly difficult for design engineers to find and utilize reusable parts in different projects (Kwapisz *et al.*, 2019). Unwanted effects of increased internal product variety might result in reduced efficiency, production lead times, order

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fulfilment, and increased complexity cost (ElMaraghy *et al.*, 2013; Martin and Ishii, 1997; Ripperda and Krause, 2017; Wilson and Perumal, 2010; Yano and Dobson, 1998).

The problem originates in the early-stage design phase, where several critical decisions are made on the product concepts. These decisions will affect every aspect of the product value chain, incurring various costs in relation to the confinement of the existing system (Fixson, 2005; Israelsen and Jørgensen, 2011; Ripperda and Krause, 2017). Thus, the design engineers making these crucial decisions should receive input from every step of the value chain. Creating an optimal knowledge base for developing new products or maintaining and improving existing products (Windheim *et al.*, 2016). However, most design decisions are based on direct cost, which usually correlates to material and labour costs, neglecting the accompanying indirect costs (Greve *et al.*, 2022). Even though direct costs, in most cases, make up the largest cost pool. For highly specialized machinery manufacturers, indirect costs might constitute up to 50% of the total cost (Ehrlenspiel *et al.*, 2007). Therefore, when seeking to optimize design decisions in product development, it would seem natural to include this information when designing solutions. However, one of the main challenges found is the difficulty in quantifying indirect costs (Schwede *et al.*, 2022).

Indirect costs, often called overhead costs, have in past research, been assessed, estimated, and allocated to specific products through many methods. Complexity cost management and Activity-based costing are just some of the most recent methods to allocate overhead costs (Hackl *et al.*, 2020; Hvam *et al.*, 2020; Kaplan and Anderson, 2004; Ripperda and Krause, 2017; Thyssen *et al.*, 2006; Wilson and Perumal, 2010). The purpose of allocating overhead costs to specific products or product groups is to assess the profitability of each product, typically with the intent of rationalizing the overall product portfolio and not specifically improving product design solutions (Hansen *et al.*, 2012). Thus, evaluating products primarily on cost data without including performance data.

Later research has made attempts to combine cost- and performance data (Schaffers *et al.*, 2022) but excluding the indirect costs. Other researchers have tried to combine methods for controlling product variety, such as modularization with allocation of indirect cost through complexity management (Greve *et al.*, 2022). However, this is mainly performed on a product variant level, not considering the whole of the product family, resulting in data with limited validity upon which design decisions can be made (Ripperda and Krause, 2017).

Some of the major challenges found in the research conducted for increasing the design engineers' knowledge in the early-stage design phase are that whole product families must be considered when evaluating product variants. Furthermore, a combination of all effects throughout the value chain due to product variety must be taken into account, and connecting the measured effects to a product, module, or part level is a complicated and resource-intensive task (Greve *et al.*, 2022; Ripperda and Krause, 2017).

Other fields of study focusing more on the data-driven part of product design with the intent of creating a firm knowledge base for semi-automated design are rarely successfully implemented in the industry when it comes to creating decision support for design engineers. Such as Chandrasegaran et al. (2013) argues for developing knowledge-aided systems to improve decision support. However, this requires extensive development and integration into the traditional engineering software to create a comprehensive representation of product development knowledge. On the other hand, focusing on extracting knowledge, experience, and designer content from historical data proves to be just as big a challenge in the research study made by Feng et al. (2020). Although many approaches exist, no one has yet fully understood the coherent effects on the product value chain based on specific design decisions (Greve *et al.*, 2022).

4. Problem statement

In the literature study, we found several challenges addressing the issue of creating a firm knowledge base for design decisions, which can be further investigated in a case study. Some of the main challenges are:

1. Taking the combination of all effects throughout the value chain into account
2. Considering whole product families when assessing product variants
3. Connecting the measured effects of product variants to a product, module, or part-level

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4. Converting measured effects and resources into quantitative data
5. Extracting the necessary knowledge from existing systems

These challenges, together with the findings in the case study, will form the foundation for the discussion in section 6. The case study presented here aims to shed light on challenges created by product variety in a manufacturer of industrial machinery and the challenges related to overhead cost allocation in a specific company. Allocating the cost of part variety in a specific product is a task yet to be fully understood leaving a clear opportunity to assess the effect and associated cost of having variance between products (Cameron *et al.*, 2010). Thus, the case study will outline the direct link between part variety and allocation of the associated indirect costs. Contributing to an extension of our existing knowledge of allocating indirect cost on a part, module, or product level. The study is focused on sales, construction, procurement, production, inventory, and installation/services. Logistics has not been part of the analysis, though many interesting challenges might have also been found here. As such, this study aims to answer the following questions:

- Q1: What challenges arise due to product variance in different stages of a company's value chain according to the literature?
- Q2: What are the observed challenges in an industry case toward creating cost transparency throughout the value chain, thereby creating better design decision support?

5. Case study

Through observation of the company's operations and systems, along with interviews with the employees and managers, certain challenges in creating cost transparency in the company have been identified to improve decision-making. In this section, challenges in each investigated step of the value chain, as presented in Fig. 1, will be described. Furthermore, an example of how product variety-induced cost materializes in each value chain step will be shown by analyzing and allocating indirect cost based on part variance for two specific products from the case company's product portfolio. The products are based on the same product architecture but made for different application areas, which separates them into two different product families. One from a product family with low variety and a minimum of customizations required (Product 1) and another from a product family with high variety (Product 2), where the product requires additional customization. As a matter of fact, to satisfy the customers' requirements, product 2 has generated seven times as many new parts compared to Product 1.

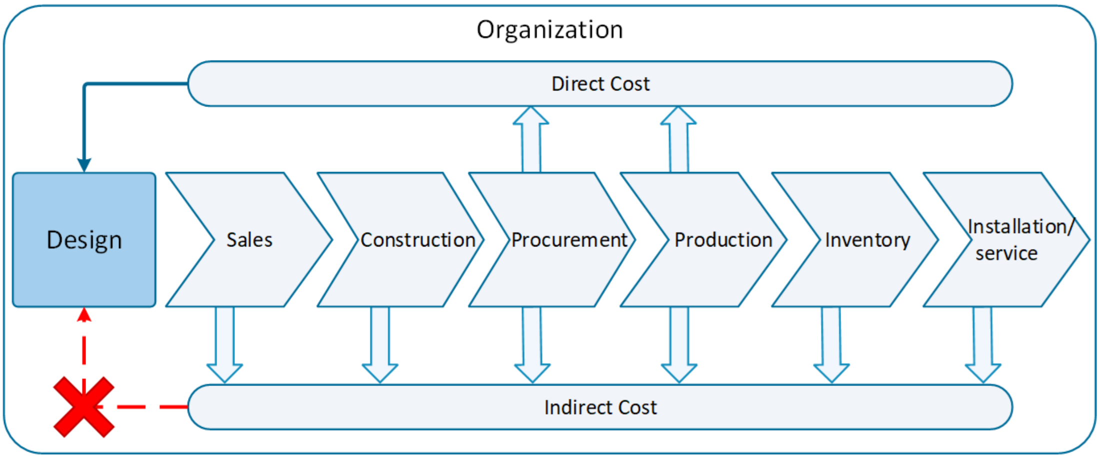

Figure 1. The value chain steps investigated, and the cost data flows observed in the company

The calculated costs are presented as percentages of the revenue made from selling them and are presented in each of the following sections. The final cost structure will be given in the summary. The cost calculation is based on the various employees' estimates of their time usage regarding the specific solution. Various other indirect costs, such as machinery depreciation, energy, etc., are not included in the calculations. As such, the estimates given in this example are conservative. Services are also excluded as these are recently sold products, and the cost generated in service is not yet applicable.

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Before diving into the challenges of each department, an issue of order follow-up should be presented. A pre-calculation is made for every order arriving at the company to estimate the expected cost and price point. The pre-calculation is based on the most recently sold similar solution. The problem is that with high product variety, the interval between similar orders is quite long. This means that material prices are obsolete and labour hours are no longer representative, resulting in additional costs than what had been estimated in the pre-calculation. In the past few years, the additional direct cost alone has often been much higher than first estimated, especially when customized solutions are made.
In the calculated example, Product 1 had additional direct cost at 2,3 % of revenue. Whereas for Product 2, the additional direct cost was 23.9 % of revenue, reducing the expected contribution margin substantially. In the current market environment, with few competitors and high-quality machinery, they manage by setting high price points. However, it is only a question of time before more companies enter the market, and then they might be obliged to lower their prices to stay competitive. Then, they will need to change their operations or gain better control over their product variety to address this problem.

5.1. Sales

From sales or marketing, the designer receives a list of specifications. They might also include requirements regarding specific suppliers if the customer has made these clear. The designer then develops a solution that fits these demands. However, as product variety grows, so does the competencies needed to sell these solutions. In this case, it takes about seven years of experience for the salesperson to understand the highly technical machinery he or she sells properly, according to their most experienced sales employee. In that time, many new variants will have emerged, making the salespeople rely on engineers for technical support, demanding resources from both sales and engineering. The time and resources the salesperson spends on creating the order specification should be considered allocated to the order or products in the order, as the salesperson's abstraction level makes it difficult to allocate them accurately to subassemblies or parts, but instead, it is allocated as overhead, making it difficult to properly allocate. For some orders, it is necessary for the salesperson to visit the customer's production site to gather the necessary information to fit their machinery with the customer's existing production lines, and specifically, in these cases, many unique variants are created. The cost generated is seen as indirect. Hence, the decision-makers are not aware of the potential issues or the size of the issue, and thus, the solutions are made from scratch each time. In the example presented, Product 2 generated twice the cost in the sales process as Product 1 did (in relative terms), as they respectively had cost at 1,2 % – and 0.6 % of revenue.

5.2. Construction

Product variance emerges in the design department firstly from customer's order specifications and from the development of new products, but another important driver of product variety in the case company is the Product Data Management system (PDM). Each product that is constructed has a unique serial number, which functions as the identification in the PDM. However, in their Enterprise Resource Planning system (ERP) product data is stored under order numbers, which makes it difficult for the designer to search for solutions across their IT systems for common or identical solutions. Instead, they manually go through an image gallery containing all former product solutions in the search for a similar product. This creates a problem since it takes about 30 minutes to draw up a new geometrically simple part, and it takes, on average on and a half hour find a part in the PDM system, according to their senior product developer. This incentivizes making new parts instead of reusing existing solutions to solve similar problems. Furthermore, there is no clear overview of which solutions demand the most resources in their department, as the cost goes into the overhead. However, there is a clear trend in resource consumption when looking at the example. Product 2 had a cost of 3.6 % of revenue from work in the construction department, and Product 1 had a cost of 1.7 % of revenue.

5.3. Procurement

When the designed solution is ready, it is sent on to purchase and production. In procurement, they receive a BOM. From the BOM, procurement and warehousing demands are determined, and the

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necessary parts are bought from suppliers. The designer learns the direct materials cost from these operations. However, increased variance leads to smaller batch sizes, affecting procurement deals. Furthermore, the number of suppliers increases (also due to customer demands for certain certification standards), and product data management becomes a growing concern. Different suppliers use different data formats and record different kinds of data, which the company then must manage. These challenges have previously not been brought to the designer's attention. The cost of maintaining product data is seen as indirect, and the cost of missing economies of scale is hard to quantify.

As mentioned previously, there are a fair amount of unforeseen costs when material is procured in the case company. The additional direct cost for Product 2 was 23,9 % of revenue. Of these 23,9 percent points, eighteen of them were additional material costs. On the opposite end of the scale lies Product 1, with an increase in material cost of only 0.6 % of revenue.

5.4. Production

The cost of labour is recorded as a direct cost to the product and its variants and hardly tells us how variance affects production. Batch sizes, quality issues, number of changeovers, and number of production processes and machinery seem to be important indicators. For instance, welding processes are a core manufacturing process in the company, but with many different types of welding processes, it also becomes increasingly likely to make mistakes, as learning curve effects decrease when complexity increases (Hackl and Krause, 2017). Furthermore, there is a desire to automate these processes, but this becomes quite challenging due to the high variance in welds and welding techniques. Again, the cost is seen as indirect and gets lost in overhead, resulting in a missed opportunity to optimize production. This challenge is also seen in the example, as Product 2 demanded additional labour hours, resulting in an additional cost of 5,9 % of revenue, whereas Product 1 only had an additional cost of 1,7 % of revenue. Production planning also seems to be affected by product variety, as found by Greve and Krause (2019). Product 2 used 2,5 % of revenue on production planning, and Product 1 used 1,2 %. Many other expenses in production could also be allocated, like depreciation, energy, etc. So far, the data has not been available in a form that could be connected to the product variants.

5.5. Inventory

There is a lack of information flowing from inventory to design. In the storage, it is common to find obsolete parts kept to satisfy service requirements for previously sold machines. Having the cost of these parts could result in designers making more long-term robust designs, where parts can be used in future generations as well as the current. Furthermore, the high number of variants in stock means more space is needed, and the workers are spending more time finding and preparing parts for production. These costs and others associated with inventory are all seen as overhead costs, and most of the data needed to allocate them to specific parts and products is simply not collected as it is not a part of the daily operations. One cost that can be easily allocated with data available in the case company, is the yearly depreciation of 5 % of the inventory's annual value, neglecting warehouse labour, opportunity cost, rent, etc. In the calculated example, this means that Product 1 has a yearly depreciation cost of 1.8 % of revenue, while Product 2 has 2,5 %.

5.6. Services

As the company's products have a lifespan of about 15 years and the products have complex software and mechanical parts, the company spends a fair number of resources on services regarding installation, maintenance, upgrades, etc. This means that parts need to be in storage for a long time and that purchasers sometimes are sent on impossible quests to gather long-gone obsolete parts from vendors. Though this information travels to both inventory and purchase, it has never been brought up with the design team. Furthermore, issues with installation are often only discovered at the customers' production facilities, where the cost of fixing it is significantly higher than earlier in the value chain, emphasizing the significance of having the proper knowledge support in the initial stages ((Martin *et al.*, 2007; Sigsgaard *et al.*, 2020). There is no best practice when allocating these additional costs, so you would need to get inventive and use unconventional metrics to produce reliable estimates (Hvam *et al.*, 2019).

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5.7. Summary of Findings

Through the analysis of the case company, several different challenges have been found, which all derive from high product variety. In sales, more technical support is needed to properly specify solutions, in construction, time is wasted searching through the PDM system, purchasers miss out on important discounts, production experience challenges regarding when new processes are needed, inventory fills up with obsolete parts necessary to fulfil service agreements, and service experience challenges with different installation principles and parts that are hard to acquire.

These challenges have been validated by a quantitative example. The cost from each step described is summarized in Fig. 2 as a percentage of the total revenue gained from the solution sold. Data sources are denoted as either qualitative (Ql) or quantitative (Qn) in the legend. The figure clearly shows that Product 1, which came from a low-variety product family, has the highest contribution margin ratio (CMR) of 57,4 %. In the high-variety case the CMR is reduced to 29 %. The sum of costs allocated, besides the direct cost, sums up to 9,8 % for Product 2. When the company eventually faces more fierce competition, they might be obliged to lower their prices, by then a difference of at least 9,2 % might hurt CMR a lot more. With a better understanding of the impacts from the product design, other solutions might have been made, which would reduce the negative effects.

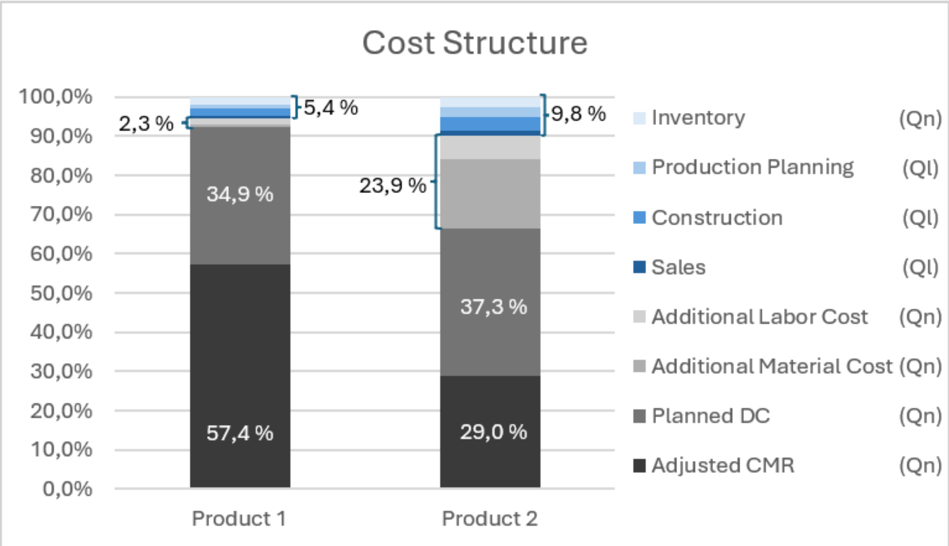

Figure 2. Cost structures of Product 1 and 2 denoting qualitative (Ql) or quantitative (Qn) data sources

Several challenges regarding the allocation of indirect costs have also been found. In general, there is a lot of information that is lost in overhead, and without proper allocation principles or quantification objects the cost is difficult to distribute accurately to products, modules, or parts. Furthermore, some costs might only make sense to allocate to one of those levels, as it might depend on the abstraction level at which the employee works. Though the part level seems to be important, as each additional new part creates additional cost at different stages of the value chain. There are also many effects, like economy of scales, learning curve effects, automation possibilities, etc., which are hard to quantify in monetary terms. Furthermore, a lot of the data needed to perform the allocations is either not gathered, as it is not a part of the daily operations of the company, or it is not available in a form that allows reliable allocations without extensive resource consumption regarding data mining and analysis.

6. Discussion

This section reflects on the challenges found in the literature, as presented in section 4, in relation to the findings in the industry case. The first challenge was about considering every combination of effects in the value chain. Choosing to only allow for a segment of the effects to influence the decision-making will create solutions based on incomplete information, leaving the designers without the required

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knowledge to understand the potential effects of their design decisions. Unless the effects can be considered negligible, although no complete generic framework for evaluating the weight of each effect in combination exists (Greve *et al.*, 2022). However, one might argue that monetary values are associated with weight. In the sense that the largest expenses might often carry the largest weight. With such thinking, material cost would seem the heaviest of effects in the case company when considering the calculated example, but here, it is important to remember that the example leaves out many effects that have not yet been quantified in this study.

The second challenge focused on assessing the whole of the product family. Limiting the scope of the evaluation will not give an accurate insight into the overall profitability of each product variant. Thus, creating monetary disadvantages between product variants depending on the product structure. Which ultimately can lead to non-optimal decision-making. Not being able to evaluate products across the whole product portfolio will leave decision-makers in the dark about the actual profitability of each product. Making them reliant on non-transparent budgeting based on traditional accounting methods, as is the case in the company. In small-scale operations, this might not result in any major issues. However, since complexity is an exponential property, working with large-scale operations could potentially result in major variety-induced costs hidden from the decision-makers. A business that competes on price will also be more sensitive to such uncertainties in the cost structure.

The third challenge of tying each measured effect of product variety to a product, module, or part-level hinders a sufficient understanding of design decisions and their associated effects for optimal decision-making. Learnings from the case study indicate that the measured effects of product variety should be allocated on different levels dependent on the value chain step. E.g., in sales, it may only be sensible to allocate cost in relation to each product variant, while in construction, costs could be allocated to a modular- or part-level, as they actually work at these abstraction levels.

The fourth challenge describes the issue of converting measured effects into a format which are comparable. E.g., not being able to quantify the effects will make it difficult to assess product variants and design solutions in relation to each other. Using time-driven approaches when converting resources into monetary values provides part of the solution for this challenge, as seen in the case study. However, some effects, like economies of scale, automation, etc., might need other quantification methods to yield the potential benefits of the design decisions.

Finally, the fifth challenge involves accessing and extracting the necessary knowledge from the existing systems. If it is not possible to extract data in a comprehensible format for decision-making, then creating a valid knowledge base for making design decisions will be difficult. Another challenge, as seen in the case study, is the required data's availability to allow reliable allocation of resources and costs. The above-mentioned focus areas share some common challenges in being resource-intensive and having a high complexity level, taking multiple factors throughout the value chain into account.

7. Summary & outlook

This paper set out to investigate the literature for effects and challenges in creating cost transparency throughout the product value chain regarding improved decision-making in product design. The literature review revealed five major challenges, which were further investigated through a case study on a manufacturer of industrial machinery. Similar challenges could be observed in the case company. However, these challenges were expanded upon with a quantified example, and when compared to the findings in the literature, a more nuanced picture of the challenges emerged. Thus, showing that the observed challenges can be somewhat mitigated using a time-driven approach, but to fully address the challenges a more comprehensive framework must be developed, accounting for different abstraction levels according to the product structure and processes throughout the company. This research study contributes to the field by extending our knowledge about allocating indirect cost on a part, module, or product level. Further research should be conducted to address the challenges found here. Effects, which are hard to quantify in monetary terms, need to be further investigated, and possible interdependencies should be revealed to create the most accurate costing models. To properly develop a new costing model, the existing methods should be investigated to find their strengths and weaknesses, in hopes of creating a more comprehensive costing framework for variant costing. Additionally, other value chain steps, such as logistics, would be reasonable to include in the model.

Data management and availability is a challenge found in both the literature and the case study. This suggests that further research should be done to find better practices, which can be practically applied in companies. The data flow between value chain steps and information systems should be considered in these studies. Since this study is based on findings in a single company, claims of generalizability are hard to make unless supported by the literature. Additional cases should, therefore, be investigated to gain a broader understanding of the requirements of creating a generic framework for variant costing. Conducting the same study across more than one company with similar problems would provide a clearer picture of the effort needed to generalize the proposal.

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