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The costs and benefits of product configuration projects in engineer-to-order companies

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Abstract

In recent decades, many engineering-oriented companies have gained significant benefits from the use of product configurators, including higher product specification quality, fewer specification errors, faster quote creation and higher quote accuracy. On the other hand, many companies also experience great difficulties in realising such benefits within reasonable costs, which in many cases makes them abandon such projects. Although the literature provides a variety of methods to support the development and implementation of product configurators, it remains unclear how to estimate the costs and benefits for different scenarios — and, from there, how to define a profitable project scope. To address this issue, this paper develops a framework to support the estimation of costs and benefits of configurator projects in connection with their scoping. The framework includes models of the relationships between costs and benefits of product configurators at three different abstraction levels: product family level, product part level, and product detail level. The framework is investigated through studies of five configurator projects, which include descriptions of the total costs and benefits of these projects. The numbers from the projects studied support the hypothesised cost-benefit models. The studies also show that there can be great variety with regard to break-even points, as one of the configurator projects became profitable after only 12 months, while two projects had yet to become so after five years.

Keywords: Product configuration; Product configurator; Mass customisation; Cost-benefit analysis; Configurator scope; Engineer to order (ETO)

1. Introduction

A product configurator is a type of expert system that supports product specification processes by providing the user with product customisation choices while ensuring that only valid combinations can be chosen. On this basis, configurators can generate bills of materials, quotes, operation plans and the like (Haug, 2007; Hvam et al., 2008). Such automation of knowledge work is made possible by the configurator's knowledge base, which includes information about product properties, product structure, production processes, costs and prices (Forza and Salvador, 2007). In this manner, product configurators are able to automate tasks previously carried out by domain experts, such as sales staff and engineers.

Automating and standardising knowledge work can achieve a number of benefits in engineer-to-order (ETO) companies. Studies have shown these benefits to include: reduced time for generating quotes, fewer errors in product specifications, less resources needed for product specification, more accurate quotes, higher similarity of sold products, better supplier communication and more (Forza and Salvador, 2002a, 2007; Ardissono et al., 2003; Gronalt et al., 2007; Mortensen et al., 2010; Haug et al., 2011; Trentin et al., 2012; Haug, 2013; Hvam et al., 2013; Stjepandić et al., 2015; Shafiee et al., 2017). Such benefits, as well as costs, are described in further detail in the subsequent section.

Although many ETO companies achieve several of the aforementioned benefits from the use of configurators, many companies also experience great difficulties in realising them and in many cases

abandon initiated projects (Ladeby and Oddsson, 2011; Haug et al., 2012; Walcher and Werger, 2011; Blazek and Pilsl, 2017). In this context, the more accurate the costs and benefits of a software project can be estimated, the easier it becomes for decision makers to avoid choosing projects that turn out to be unprofitable and choosing the ones that become profitable (Alshawi et al., 2003). However, although the literature provides a variety of methods to support the development of configurators, including overall guidelines for scoping such projects, it remains unclear how to estimate costs and benefits of product configurators when defining project scopes. To address this issue, this paper posits the following research question:

What are the relationships between configurator project costs and benefits in ETO companies?

In this context, it should be noted that product configuration is a concept that involves different types of applications. In itself the term "configuration" refers as the "relative arrangement of parts or elements" (Merriam-Webster Dictionary), for which reason configuration does not necessarily involve the use of configurators (i.e. software that supports configuration processes). This paper, however, focuses only on software-supported configuration processes, for which reason when using the term "product configuration" it refers to such.

The remainder of the paper is structured as follows. First, relevant literature is discussed. On this basis, the paper develops a framework for determining the costs and benefits of configurator projects. Next, the usefulness of the framework is investigated through studies of five configurator projects at an ETO company. The paper ends with conclusions being drawn.

2. Literature review

To lay a foundation for addressing the research question, searches for two themes in the product configuration literature were carried out: (1) costs and benefits in configurator projects, and (2) configurator project scoping.

2.1 Configurator project costs and benefits

As mentioned in the introduction, this paper focuses on the use of configurators in ETO companies. Here it should be noted that product configurators can be divided into two overall types, namely ones used for the specification of products that are traditionally mass produced and those that are traditionally engineered (Haug et al., 2009). Configuration of products that are traditionally mass produced typically implies relatively low configurator knowledge base complexity as compared to configurators aimed at engineered products, which can include thousands of constraints determining how components and properties may be combined. This distinction may also be explained in terms of the customer order de-coupling point (CODP). One of the most frequently applied distinctions between CODP's (Wikner & Rudberg, 2001; Olhager, 2003) include: Engineer-To-Order (ETO), Make-To-Order (MTO), Assemble-To-Order (ATO), and Make-To-Stock (MTS). In relation to the use of configurators, mass producers will typically add some variety to their MTS-products (ElMaraghy et al., 2013), while ETO companies transform their products from ETO product to ATO products by predefining all possible component choices as well as the constraints that determine how they may be combined (Haug et al., 2009).

In an ETO context, the costs associated with configurator projects concern both the initial costs of making the configurator and the running costs of operating and maintaining the configurator (Pisello & Strassmann, 2003). However, only a few researchers have addressed cost factors in relation to product

configuration (Shafiee, 2017). One example is Hvam (2006a), who presented a case study of a company producing customised process plants in which the development and implementation costs were approximated. However, Hvam did not link these costs to the direct benefits achieved through the use of the product configurator.

Forza and Salvador (2002a) and Haug et al. (2012) discussed the pros and cons of applying configurator software shells versus development of such software. While software shells typically involve the costs of buying the software, as well as running license costs, the development of a configurator from scratch obviously eliminates such costs but can, on the other hand, be an extremely time-consuming and resource-demanding endeavour. Increased availability and decreased costs of configurator shells seems to have led to these typically being applied in ETO company configurator projects — at least this is the case in the majority of the studies described in the literature (e.g. Forza and Salvador, 2002a, 2002b; Hvam et al., 2008, 2013; Haug et al., 2011, 2012; Shafiee, 2017).

Besides the costs related to software acquisition, the literature describes several configurator project tasks that produce man-hour costs. One example is Haug et al. (2012), who mentioned the tasks knowledge elicitation (acquisition), knowledge translation, knowledge formalisation, knowledge implementation (into a configurator), knowledge documentation and configurator-documentation synchronisation. Hvam et al. (2008) mentioned the tasks of process analysis/redesign, product analysis/redesign, object-oriented analysis/design (model formalisation, and definition of user and systems interfaces), configurator development, organisational implementation (training and communication) and maintenance (further development and documentation).

As compared to the costs associated with configurator projects, their benefits have been described in much more detail. In particular, three types of benefits are mentioned in the literature: (1) time reduction (man-hours and lead time), (2) product specification quality improvement and (3) sales increase.

Perhaps the most oft-mentioned benefits of product configurators in the literature concern time reductions in the form of reduced man-hours and faster creation of product specifications. In this context, a number of single case studies involving quantified descriptions of reductions in lead time and man-hours have been carried out. These include Forza and Salvador (2002b), who found that the time required for activities in the tendering process was reduced from 5–6 days to 1 day; Forza el al. (2006) found that time needed to make quotes was reduced from 1–2 days to a few hours, and technical specifications from 2.5 days to a few minutes; Hvam et al. (2004) found that the lead time for generating tenders was reduced from 15–25 days to 1–2 days, and the time required for engineering in the quotation process was reduced from 5 weeks to 1–2 days; Hvam (2006b) found that the time spent preparing offers and production instructions was reduced to almost nothing, and the delivery time was reduced from 11–41 days to 1 day; and Hvam (2006a) found that the resources required to generate the quotations were reduced by 50%.

There are also a few studies involving multiple companies which report time reductions. These include Hvam et al. (2013), who conducted four case studies in which the average lead time required to generate an offer was reduced by 94–99%, and the resources needed to create product specifications were reduced by 50–95%. Furthermore, Haug et al. (2011) conducted a survey of 14 companies where the average time required to generate proposals was reduced by 85.5%, and the average amount of man-hours used in the configuration process was estimated to be reduced by 78.8%.

Another oft-mentioned benefit from configurator projects is improved quality of product specifications, which can produce cost reductions through fewer errors and reduced need for communication. Such benefits may be attributed to more standardised and exact calculation methods. A number of single case studies provide quantified descriptions of specification quality benefits. In this context, the studies by Forza and Salvador (2002a; 2002b) found that errors in configuration information were reduced to almost nothing; Hvam (2006b) found that the number of assembly errors was reduced from 30% to less than 2%;

Sviokla (1990) found that the accuracy of product specifications was increased from 65–90% to 95–98%; and Yu and Skovgaard (1998) found that the configuration accuracy was increased to 100%.

A type of benefit also mentioned in the literature is increased sales, which is a result of configurators enabling salespersons to produce quotations significantly faster and thus offer quotes to a higher number of customers (Heatley et al., 1995; Heiskala et al., 2007; Hvam, 2006a; Hvam et al., 2013). However, although increased sales is an oft-mentioned type of benefit, the impact remains largely unaddressed, and quantifications of the relation between product configurators and increased sales are absent in the literature.

Finally, Haug (2013) mentioned the potential benefit of improved supplier communication. This benefit is produced through the creation of common knowledge models between a company and its suppliers, implying that many discussions and disagreements can be avoided. Although a configurator would not be needed to produce this benefit, such common models are often part of configurator projects.

2.2 Configurator project scope

Deciding on the focus of a configurator is a central part of the scoping of a configurator project. In this context, configurators can be divided into two main categories (Aldanondo, Hadj-Hamou, Moynard, & Lamothe, 2003): 1) commercial focus, i.e. processes carried out by sales teams; and 2) product development focus, i.e. processes carried out by R&D teams. A similar distinction was made by Forza and Salvador (2007), who distinguished between commercial and technical configurators. They defined the commercial configuration process as “all the activities carried out to identify the complete and congruent commercial description of the product that best fits customer requirements” and the technical configuration process as “all the activities that generate the documentation of the product variant based on the commercial description of such variant”. Another type of configurator distinction was proposed by Haag (1998), which concerns high-level and low-level configuration. In high-level configuration, an external problem solver, usually a salesperson or customer, interacts with the configurator to make creative decisions, while low-level configuration is a manufacturing-oriented, non-interactive, procedural process that selects the necessary parts, checks their availability and determines the necessary routings at a level of detail that is no longer interesting to the customer (Haag, 1998).

An important part of determining the scope of a configurator project is to clarify stakeholder requirements. Stakeholder requirements can be divided into functional and non-functional requirements (Basili & Weiss, 1984). Functional requirements concern the functions that a system must be capable of performing, and non-functional requirements concern how the software will work, as opposed to what it will do (Ebert, 1997), i.e. issues such as the reliability, consistency and maintainability of configurators. In relation to stakeholder types in product configurator projects, Nellore et al. (1999) mentioned top management, brand/marketing management, research and development, after sales/service, project management and manufacturing; Forza and Salvatore (2002a) mentioned design, manufacturing and sales; and Hvam et al. (2006) mentioned project sponsors, project managers, technical facilitators, model managers, domain experts (product developers, engineers, production experts or future users), change managers, process managers and programmers.

3. A product configuration cost-benefit framework

The framework for understanding the relationships between the costs and benefits of product configurator projects is developed in two steps. The first step concerns establishing some basic definitions

based on previous research (Section 3.1 and 3.2). The second step applies these definitions to construct models of the relationships between costs and benefits in product configurator projects (Section 3.3 and 3.4).

3.1 Costs and benefits of product configurators

As described in the literature review, there are several types of costs and benefits associated with configuration projects. To produce an overview of these, a couple of basic distinctions can be applied. As described in the literature, the development of configurators involves costs related to both material acquisitions (e.g. configurator software) and use of human resources (e.g. knowledge base modelling) (Hvam et al., 2008; Haug et al., 2012). The material costs include software purchases, software licenses, hardware and similar items, while the human resource costs can involve both product and software development. In relation to product development, it should be noted that often the solution spaces of the product families in focus are too extensive to be implemented into a configurator. Thus, product preparation can include reducing the solution space by reducing the variety of the parts in a product family (Hvam et al., 2008; Haug et al., 2011). Such preparation can in itself produce benefits, for example, less component management and reduced item costs through larger purchase quantities of similar items (Hvam et al., 2008). However, it may obviously also be the case that the product assortment is ready for configuration at the start of a project, in which case only minimal product-related development costs would be incurred.

Both of the above-mentioned cost types can be divided into costs that are incurred before launching the product configurator (prelaunch costs) and the running costs thereafter (operating costs). This is illustrated in Figure 1.

	Material costs	**Human resource costs**
Prelaunch costs	▪ Configurator software purchase ▪ Other software purchases ▪ Computers ▪ Etc.	▪ Product redesign ▪ Configurator development ▪ Initial user training ▪ Etc.
Operating costs	▪ Configurator software licenses ▪ Other software licenses ▪ Computer replacements ▪ Etc.	▪ Product model maintenance ▪ Configurator maintenance ▪ Ongoing user training ▪ Etc.

Fig. 1. Cost types in product configuration projects.

With regard to the benefits of configuration projects, the ones identified in the literature may be divided into resource use and sales performance benefits, i.e. benefits related to resource savings and increased turnover. The resource-related benefits emerge from automating specification work, previously carried out by domain experts, and they concern aspects such as less time needed for quote creation, less time needed to create bills of materials and less need for communication between sales staff and engineers. The sales-related benefits are being able to provide more quotes, improved customer communication and more accurate quotes. Unlike for costs, the distinction between a prelaunch and an operating phase is not relevant here, since benefits only occur during the operating phase. This is illustrated in Figure 2.

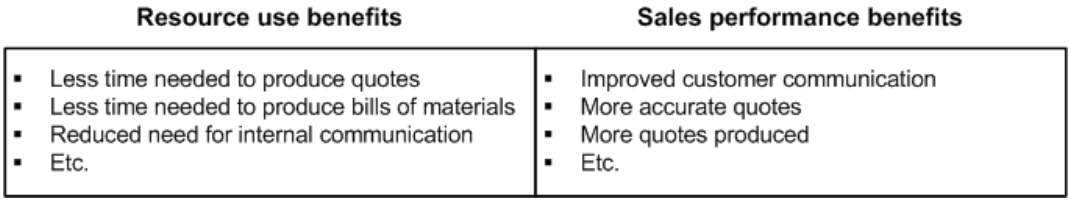

Fig. 2. Benefit types in product configuration projects.

As described in the literature review, the reported type of benefits from the use of configurators in ETO companies varies. However, based on benefits mentioned in the described literature, the following measures (or performance indicators) of benefits can be extracted:

1) Man-hours per quote in engineering
2) Man-hours per quote in sales
3) Time from customer request to quote
4) Number of quotes produced
5) Quote accuracy (costs in quote calculation versus actual costs)
6) Numbers of errors in quotes
7) Quote data completeness (number of missing pieces of information)
8) Numbers of errors in BOM's
9) BOM data completeness (number of missing pieces of information)
10) Sales increase (configurator-produced)
11) Quality of supplier communication
12) Quality of customer communication

Although the first 10 of the 12 identified performance indicators mentioned above are quantitative, they differ in terms of the ease and reliability in measurement. While items 1 to 5 concern data normally registered in IT systems (such as ERP systems), items 6 to 10 typically are not registered, and it may require a significant amount of resources to measure these, unless using rough estimates, as done in some previous studies (e.g., Hvam, 2006a; Haug et al., 2011). Thus, there are typically more uncertainty associated with such indicators. In relation to item 10, "sales increase", the issue with this measure is that, although sales numbers may be registered in IT systems, it may be hard to determine if an increase of sales is a result of using the configurator or other factors, such as market fluctuation. Finally, quality of supplier and customer communication are based on subjective evaluations and may concern different aspects. Thus, there may be validity issues related to this type of indicators.

3.2 Identifying a profitable product configurator scope

The costs and benefits of product configurators are consequences of the project scope, i.e. the decisions on which product variants the configurator should cover and which it should not. Since different project scopes imply different costs and different benefits, the main challenge is to identify a scope with as good a benefit-cost ratio as possible, obviously, under consideration of the risks related to such scenarios. As shown by previous studies, this scoping may be understood as taking place on three abstraction levels (e.g. Edwards et al., 2005; Mortensen et al., 2010; Haug et al., 2011; Ostrosi et al., 2012; Hvam et al., 2013; Shafiee et al., 2017):

(1) Product family level: Which families should be included?
(2) Product part level: Which parts (here referring to "whole-part" relationship) should be included?

(3) Product detail level: Which details (i.e. attributes) about parts and their relationships should be included?

These three levels are illustrated in Figure 3 and subsequently explained.

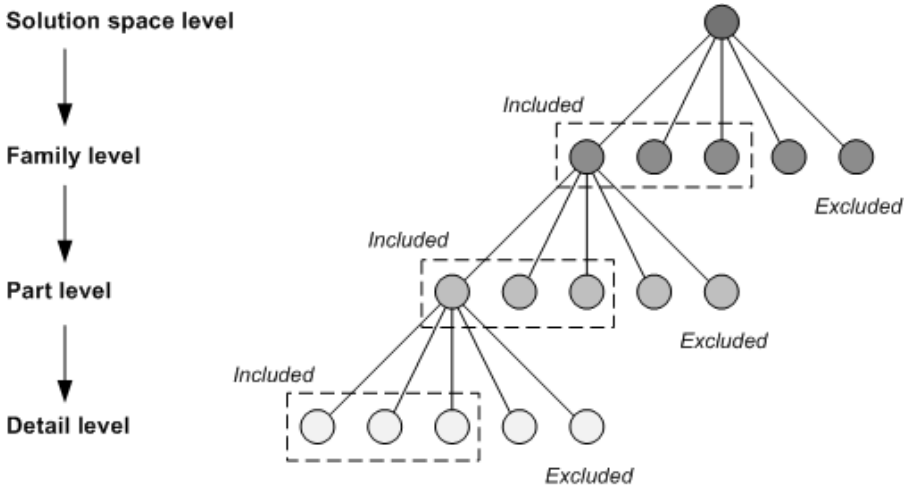

Fig. 3. Levels of scoping of product configurators.

At the top level of Figure 3 is the company's product solution space, i.e. all the imaginable product variants that the company could and would produce. Inside this product solution space would often be a set of product families, i.e. a "group of products derived from a common product platform", where the product variants within the family "use similar or same production processes, have similar physical characteristics, and may share customer segments, distribution channels, pricing methods, promotional campaigns, and other elements of the marketing mix" (BusinessDictionary, 2018). Some of these product families are more suitable to be included in configurators than others. This, for example, depends on whether they have a large enough sales volume for the configurator to be able to produce significant benefits and whether the family is adequately configurable (e.g. consisting of enough standardised parts, as opposed to custom parts).

The "product part level" concerns the parts (i.e. modules and components) of which a product family consists. Thus, the question is, which parts should be included in the configurator, and which parts should be left out? The complexity here is a result of variety, i.e. situations where there is a choice between different components. In the case of a producer of customised cars, this could, for example, involve different engine or seat types. The choice here is not whether to include seats and an engine, but which types of engines and seat variants it should be possible to choose from. Each additional variant represents one more item to manage both in relation to the production of the product and the knowledge base of the configurators. The choice of which part types to include in the configurator solution space and which to exclude depends on, for example, how often these are chosen and how profitable they are. In other words, a rarely chosen part may be costlier to include in relation to implementing and maintaining its information than the benefits that could be derived from doing so — and if a company has a higher profit margin for certain part types, it could make sense to exclude some of the least profitable parts. Furthermore, "pushing" customers towards choosing more similar modules and components can give rise to more efficient purchases and greater order similarity, which can reduce costs (Forza and Salvador, 2002a; Mortensen et al., 2010; Haug, 2013; Shafiee, 2017).

The "product detail level" concerns the level of detail of the descriptions of modules, components and their relationships, i.e. how many attributes should be included about each part and relationship. In an extreme case, a configurator could include no details about parts (besides part names), but merely let the user choose different parts (under restrictions by constraints) until a configuration of a product has been

made. On the other hand, in many cases some information about chosen parts would be useful for making such choices and later producing the product. In the case of a producer of customised cars, this could concern, for example, whether the configurator should include information about the number of cylinders and horsepower so that this can be given to the customer during the configuration process. Additionally, information about, for example, engine dimensions could be relevant, so that this would automatically be included in the bill of materials for the production staff who are to produce the customised car. However, if such information is easily accessible elsewhere (and it is not used during the configuration process), it may not be profitable to include it in the configurator, given the extra information maintenance cost.

In every configurator project, there are more profitable scopes than others with regard to the included product families, part types and part details. Identifying the optimal scope is obviously close to impossible, but aiming for this would always be the goal. Thus, the next subsections discuss how to identify the right scope of the product family, product part and part detail levels.

3.3 Cost-benefits at the product family level

To understand the costs and benefits at the product family level, the previously made distinctions between materials versus human resource costs and prelaunch versus operating phases can be applied. This is illustrated in Figure 4, which shows a hypothesised model of the development of costs and benefits for a single product family over time. As seen in the model, some costs have been incurred before the start of the prelaunch phase, namely material acquisitions. Obviously, material acquisitions could also take place later, but to simplify communication, they have been placed here. Then, during the prelaunch phase, the costs rise as the configurator is developed. Having launched the configurator and entered the operating phase, running material costs (in particular, licenses) and human resource costs (maintenance and further development) are incurred. It could be expected that these running costs would gradually get smaller over time, as less maintenance and further development are needed after initial major adjustments. As also seen in the model, during the prelaunch phase, no benefits are obtained, while during the operating phase, benefits are increasingly achieved until the use of the configurator gets normalised, after which relatively constant benefits could be expected.

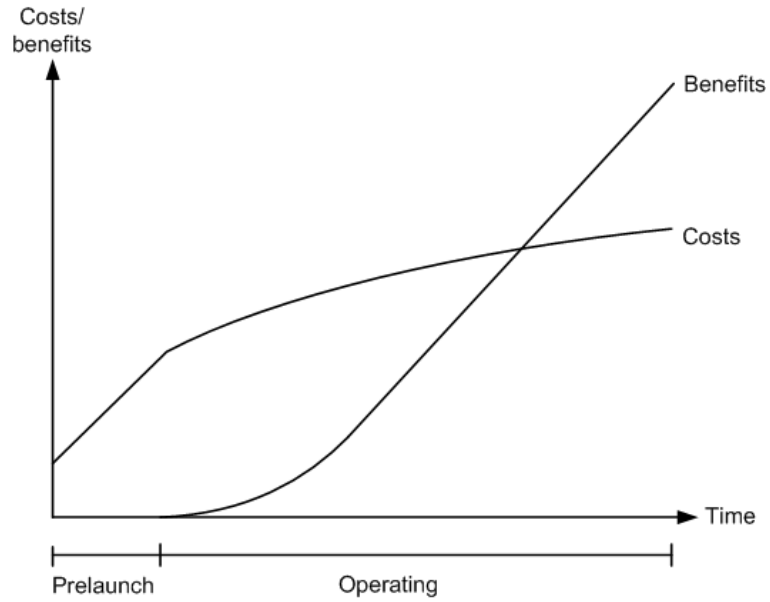

Fig. 4. Costs and benefits for a single product family.

Having illustrated costs and benefits for a single product family, it should be noted that the costs per product family should not be viewed in isolation, since many of the start-up costs from implementing the first product family are eliminated for the next product family. In the material costs dimension, a large part of the costs would be constant regardless of whether one or several product families are modelled in the configurator software, i.e. costs related to the acquisition of software and hardware. Thus, the cost curve for software costs will be relatively high for the first product family but will decrease for each additional product family added. In relation to the human resource costs, assuming each product family is about the same level of complexity, there could be a slight cost reduction for each product family added, stemming from reuse across product families, improved product modelling skills, improved product change implementation skills, etc.

The observations described above are illustrated in Figure 5, which shows how adding a second configurator would reduce initial material costs, as well as prelaunch and operating costs, because of synergy effects.

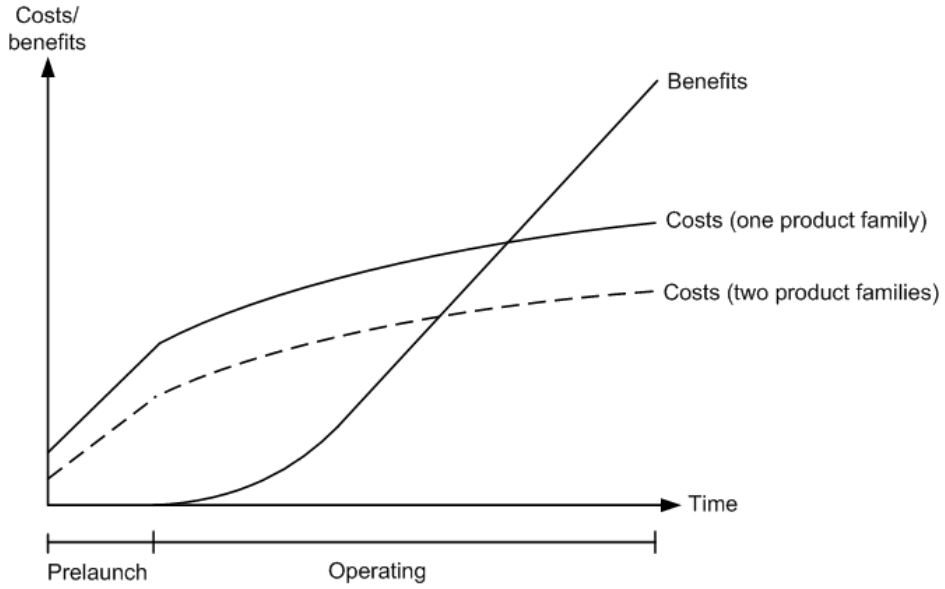

Fig. 5. Costs and benefits at the product family level.

3.4 Cost-benefits at the product part and detail levels

Evaluating which product families to implement in configurator software requires estimations of the costs and benefits of each product family. Such costs and benefits are determined by how much of the solution space of this product family is included. As mentioned earlier, in some cases certain part variants are so rarely chosen that the administration of these (both physically and in the knowledge base) is costlier than the specification resource savings from offering these choices, and in some cases it makes sense to offer only the most profitable parts or aim to obtain benefits from a more standardised product assortment.

In relation to the costs of adding variety in a product configurator, there are factors pulling in both directions. More specifically, more variety implies more complexity and thus relatively more work needed to maintain the configurator. On the other hand, with increased variety, it becomes increasingly possible to maintain more elements at a time, thereby reducing costs. For the benefits produced by a configurator, if it supports too small a part of the solution space, it does not become the norm to use it when specifying products, which creates a risk of it not being used even in the cases it does support. In other words, the configurator needs to support a certain amount of variety for it to be useful. On the other hand, if the most relevant product choices are added first, then the more recent added variety is used less often, thus

producing decreasing benefits. Based on these assumptions, the benefits of adding variety would be low to a point where it increases as the configurator begins to support adequate variety for it to be useful. Next, at some point, the benefit of extra variety decreases, as this variety concerns increasingly rare uses. This is illustrated in Figure 6, where the optimum is placed where adding additional variety/detail stops being profitable.

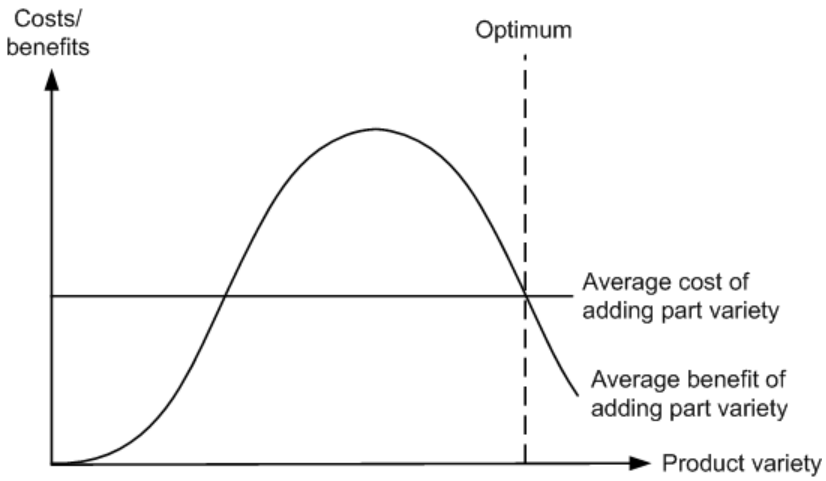

Fig. 6. Costs and benefits of adding variety and detail.

It may be hypothesised that the logic of the product part level is similar to that of the product detail level, since for details to be useful, a certain amount of detail is needed, while at some point adding more detail would have decreasing value. Thus, the benefits of adding detail would start by increasing slowly, after which they would increase more when getting to the point where there are adequate details for them to be really useful. At some point all the details needed to carry out relevant tasks are present, except for in special cases, and therefore additional details offer less value, implying that the benefits of adding more detail begin to decrease. Thus, the curve for costs-benefits for product detail may be assumed to unfold in the same way as for product variety, as illustrated in Figure 6. The subsequent sections explore this assumption.

4. Research method

Empirical studies were conducted to investigate the relevance and usefulness of the proposed framework. Given the complexity of the subject matter, a qualitative approach was chosen in the form of a case study approach (Yin, 2009). More specifically, studies of five configurator projects were carried out at a large Danish ETO (engineer-to-order) company, which produces chemical processing systems. The case company was chosen because it: (1) offers highly engineered and complex products, (2) had recently implemented several configurators, (3) measured/estimated costs and benefits of configurator projects, and (4) offered a unique level of access to project data.

For the five configurator projects, the researchers were given access to cost and benefit sheets associated with the projects, as well as a set of charts showing the relationships between costs and benefits in the five projects over five years (described in further detail in the subsequent section). To explain this data and to acquire additional information about the projects, interviews with the four project managers of the five projects were carried out. Three to four 20-30 minutes interviews were conducted with each project manager. Besides being in charge of the projects, the project managers also had roles as business

analysts and knowledge engineers and thus were also competent in relation to more technical project details. The interviews were carried out over a period of five months.

An overview of the five projects is provided in Table 1. All the projects focused on the development of sales configurators.

Table 1. Projects studied

Project	Project start (development)	Prelaunch project duration	Relative complexity
1	Jan. 2014	3 months	High
2	Aug. 2014	11 months	Low
3	Sep. 2014	4 months	Medium
4	Aug. 2015	6 months	High
5	Aug. 2015	6 months	Medium

5. Case studies

Access was granted to cost and benefit data for the five projects. These numbers are shown in Figure 7. Here it should be noticed that the graphs shown in Figure 7 have been drawn on top of screenshots of the actual charts provided by the company (currency has been converted from DKK to EUR). It should also be noted that:

1) The company based the benefit curves on analyses of benefits after one year of operating, after which a linear graph was made, based on the assumption of constant benefits.
2) The costs during the prelaunch phase were only analysed once, except in Project 2, where this was done twice because of a change of configurator scope. This explains the linear graphs for the prelaunch phase in the Project 1, 3, 4 and 5, and the broken line in Project 2.
3) The costs during the operating phase were analysed after one, two and three years. Based on these numbers the curved graphs for the operating phase were drawn.

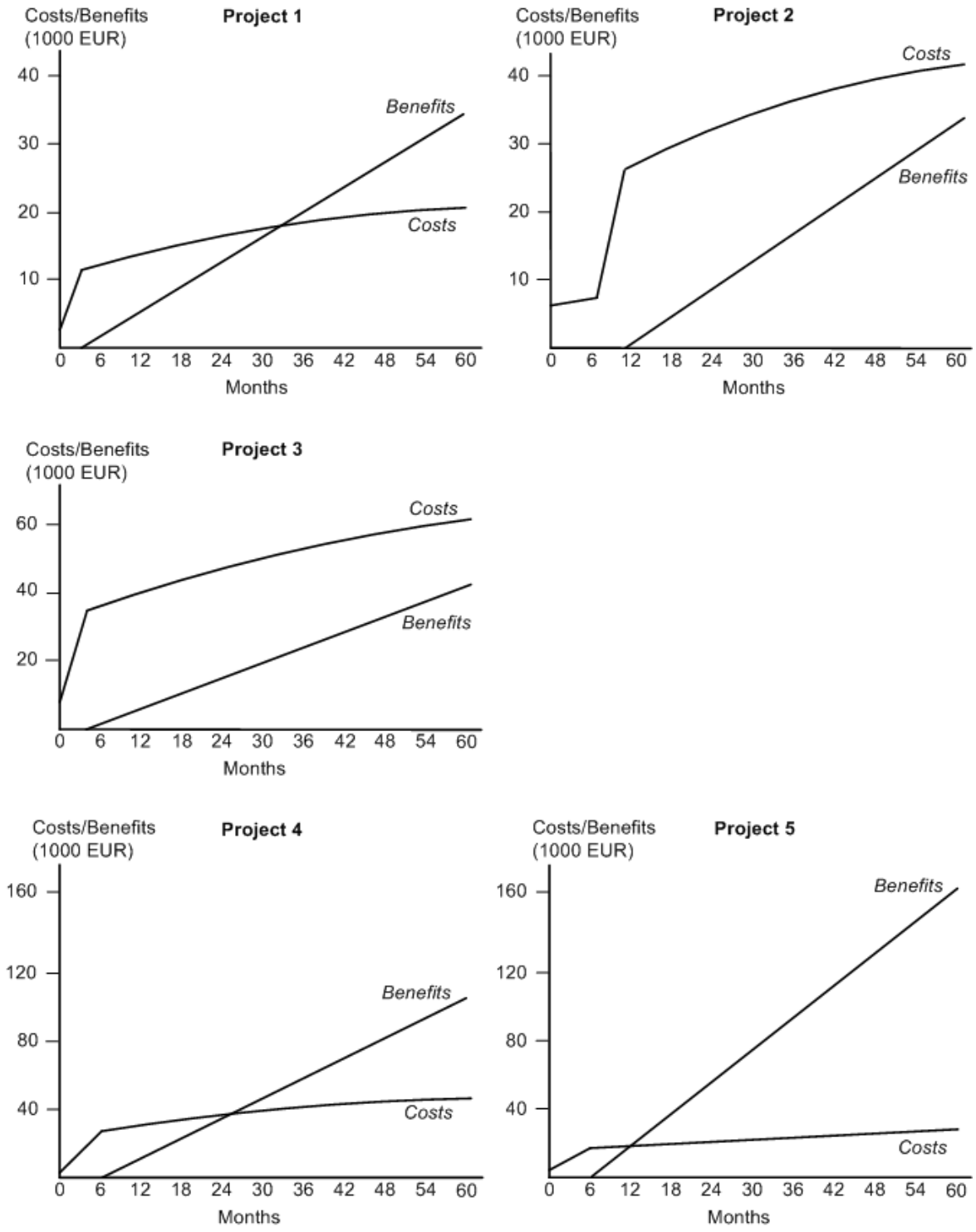

Fig. 7. Costs and benefits in the projects studied.

As seen in Figure 7, the five charts from the projects studied support the hypothesised model of relationships between costs and benefits at the product family level (Figure 4). Figure 7 also shows that Projects 2 and 3 are yet to become profitable, while the other three became so after 12 to 32 months. However, based on the estimated curves, Projects 2 and 3 will become so in the near future.

Based this data provided by the company, the distribution of implementation and operating costs are shown in Tables 2 and 3. In the numbers provided by the company, the material costs included software acquisition and licence costs, as no other major material investments were needed. In relation to the implementation costs, it should be noted that the same configurator software was used across projects and thus this software acquisition cost was divided across the five projects. The human resource costs in the implementation phase included man-hours spent on building the configurator knowledge base, creating user interfaces and other IT tasks, while in the operating phase the human resource costs included the man-hours spent on maintenance and further developing the configurator knowledge base and user interfaces.

Table 2. Prelaunch costs

	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Material costs	10%	84%	6%	6%	11%
Human resource costs	90%	16%	94%	94%	89%

Table 3. Operating costs

	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Material costs	33%	51%	18%	21%	33%
Human resource costs	67%	49%	82%	79%	67%

When comparing the projects in Table 2, it is seen that Project 2 has relatively high material costs compared to development costs. The reason for this is that the product family in Project 2 involved very few rules but mainly offered part selections, knowledge which was largely already documented at the project start. Thus, the project required minimal knowledge acquisition and product modelling work. An observation from these numbers is therefore that, in cases of high configurator complexity, the development costs vastly exceed the software costs, while with low complexity, the material costs are highest.

As seen in Table 3, for the low-complexity project, Project 2, material costs in the operating phase constituted a smaller amount of the total costs compared to the prelaunch phase. On the other hand, for the four medium-to-high complexity projects, the material costs constituted a larger amount of the total costs in the operating phase compared to the prelaunch phase. This may be explained by the majority of the human resource costs in the prelaunch phase in projects of higher complexity relating to building model structures (defining the rules/constraints between model elements), while updating prices and single components requires relatively less effort. On the other hand, in low-complexity projects, building the model structures requires relatively little effort, and therefore the efforts required in the operating phase are relatively high compared to the prelaunch phase.

Resource use benefits were calculated using the numbers registered by the company included reductions in man-hours used for sales and engineering work (for creating quotes), while the sales performance benefits were estimated based on the total sales numbers and the extent of configurator use. The distribution of resource use and sales performance benefits are shown in Table 4.

Table 4. Benefits

	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Resource use benefits	86%	91%	76%	82%	71%
Sales performance benefits	14%	9%	24%	18%	29%

As seen in Table 4, the resource use benefits constitute between 71% and 91% of the benefits. One reason for the resource use benefits being relatively high in Project 2 compared to the sales performance benefits was that the quotation creation time for this product was already somewhat lower than for the other configurators. Therefore, it did not produce the same amount of sales performance benefits.

In relation to the costs and benefits at the product family level, the approach chosen by the company can be described as an inductive approach. More specifically, the company had decided on a strategy where a configurator was developed for seemingly the most profitable and configurator-ready products, after which, based on evaluations of their performance, the next configurator projects were launched. This process was to be ongoing until the profits from making an additional configurator became too small. As previously illustrated in Figure 5, prelaunch software costs may become smaller each time a new project is initiated, assuming that the software is a one-time acquisition. This was also the case for the five studied projects where the software acquisition costs were divided across projects.

The amounts estimated by the project managers for product family coverage at the part and detail levels for the five projects are shown in Table 5.

Table 5. Coverage at the product part and detail levels.

	Part level		Detail level
Project	**Coverage***	**Minimum****	**Coverage*****
1	90%	80%	80%
2	50%	50%	50%
3	80%	80%	60%
4	90%	80%	80%
5	70%	60%	60%

* Estimated amount of sales from the product family supported by the configurator

** Estimated amount of coverage needed to ensure that the sales staff uses the configurator

*** Estimated amount of details included compared to the final bill of materials

In neither of the projects, cost models for different project scopes with regard to variety and detail were made. According to all the project managers, this would not have been a fruitful approach, since such estimates would be associated with too much uncertainty to be useful. Instead, based on demands from users (sales staff, top management and engineers) and sales history, variety and detail levels that ensure that the configurator could support the most common types of product variants were chosen. These initially offered levels of variety and detail were then continuously adjusted by removing rarely used elements and adding needed, but not yet included, elements.

According to the four projects managers, if the part level coverage offered by a configurator is too low, sales staff could be inclined to not use it at all, even in the cases it would support. On the other hand, having too much variety would imply excessive configurator development and maintenance costs. In other words, the perceptions of the four project managers greatly support the hypothesised model at the product part level (Figure 6). To identify a profitable middle ground in relation to product variety while being able to respond to user requirement, in all five projects, the primary focus was first to ensure that minimum required coverage was achieved. Then, the coverage was to be increased until the point at which costs of adding further variety would exceed the benefits of doing so.

In relation to the detail level, the four project managers argued that a consequence of too little detail could be that too much information-gathering work needed to be carried out upon having configured a product. It was also pointed out that too little information about configured products could imply ambiguity with regard to product choices, which could lead to errors in products produced. Thus, according to the mangers, too little detail could reduce the benefits and even produce additional costs. On

the other hand, according to the project managers, including too much detail would imply that the configurators becoming highly resource-demanding to maintain, which would diminish the profitability of the projects. In other words, the perceptions of the four project managers support the hypothesised model at the product detail level (Figure 6).

6. Conclusions

To address the lack of knowledge about relationships between costs and benefits in the product configuration literature, this paper developed a theoretical framework that describes them. This was done by first making some central distinctions between cost and benefit types. Second, the paper proposed that scoping of product configurator projects may be perceived as occurring on three abstraction levels: (1) product family level, (2) product part level and (3) product detail level. The paper then illustrated the logical relationships between costs and benefits on these three levels.

To investigate the usefulness of the framework, five configurator projects were studied. These case studies supported the hypothesised models of the relationships between costs and benefits on the three abstraction levels: product family level, product part level, and product detail level. Although these three models were only tested in five projects and at the same company, this does not mean that the findings cannot be generalised to other ETO companies. More specifically, it should be considered that the projects involved different managers, developers and users, as well as very different product types. Given the fit between propositions and practice in all five cases, as well as the argumentation provided and links to existing studies, there is no apparent reason to believe that other cases would contradict the content of the proposed framework. However, more studies are needed to confirm this.

Other relevant findings from the projects studied include that, in cases of relatively high configurator complexity, the configurator development costs vastly exceeded the software costs, while in the project with low configurator complexity, the material costs exceeded the development costs. Furthermore, it was found that in higher complexity projects, the material costs constituted a larger amount of the total costs in the operating phase than in the prelaunch phase — while in low-complexity projects, the opposite was the case. This was explained by configurator maintenance efforts appearing to be relatively low compared to development efforts for high-complexity configurators, while maintenance efforts are relatively high compared to development efforts for low-complexity configurators.

The main contribution of the paper is the three models of the relationships between costs and benefits of product configurators based on the projects scope, which were supported by five case studies. Such models have not previously been defined in the configuration literature (according to carried out literature searches), although costs and benefits frequently have been discussed. Another substantial contribution of this paper is to provide the actual numbers for the total costs and benefits of configurator projects. As the literature review of the paper showed, this has not been done by existing research. The paper, thus, contributes with new insights into the profitability of configurator projects as well. Finally, a minor contribution of the paper is the categorisations of costs and benefits of product configurator projects. As shown by the literature review, existing discussions of such costs and benefits focus on different aspects, while failing to consider others. The definition of these categories may stimulate future studies of configurator projects to apply a broader perspective on costs and benefits.

Future research needs to further explore costs and benefits in configurator projects, since other cases may involve aspects not encountered in the five projects studied. As demonstrated by this paper, the proposed framework provides a useful means for organising such studies.

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