INTRODUCING A FRAMEWORK TO GENERATE AND EVALUATE THE COST EFFECTS OF PRODUCT (FAMILY) CONCEPTS

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ABSTRACT

Product concept generation and evaluation are critical for the success of new product developments (NPD) because managers need to select the most profitable product concepts. However, current approaches can be restricted to single products and do not cover product families' effects. Similarly, they do not necessarily capture all requirements and usually lack extensive cost analyses. Thus, this paper proposes a framework supporting product concept generation and evaluation by providing an accessible conceptualization to overcome the limitations. Using the so-called Extended Axiomatic Design (EAD) supports designers and managers to configure the requirements across product concepts' various domains while concurrently evaluating their economic consequences. The study applies the framework on a simplified case of a bottle manufacturer to conceptualize four product concepts. The case illustrates how the EAD can be used as a virtual testbed to generate and evaluate new product concepts. Finally, designers and managers can make more informed decisions about product concepts by considering their economic and engineering selection criteria to select the most profitable NPD project configuration.

Keywords: Product concept framework, Product families, Business models and considerations, Product modelling / models, New product development

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1 INTRODUCTION

The generation and evaluation of product concepts are crucial to identify and select the most profitable new product development (NPD) projects to ensure firms' competitiveness in the long run (Markham, 2013). A product concept is an early prescription of requirements for potential NPD projects, outlining how a product or service will satisfy customers (Brown and Eisenhardt, 1995). Targeting new customers, for example, requires choices regarding products' functions, components, product family design, production technology, and suppliers (Ulrich and Eppinger, 2003), resulting in a myriad of potential configurations. Economic evaluations are therefore necessary at an early stage to define promising configurations and to select the most profitable product concepts for NPD.

Current approaches for product concept generation and evaluation are, however, restricted to single products (e.g., Suh, 2001, Gonçalves-Coelho and Mourão, 2007), do not necessarily capture all requirements (e.g., Meßerschmidt et al., 2020), and frequently lack economic rigor when considering cost effects (e.g., Campagnolo and Camuffo, 2009). Generating product concepts draws on a large conceptual foundation and guidance from various studies (e.g., Otto et al., 2016, Krause et al., 2014, Simpson et al., 2014, Moon and Simpson, 2014), but the literature has not addressed evaluations of these concepts to a great extent. Little attention is still paid to product family design's cost effects when determining product concepts' economic consequences. For example, product concept generations usually come with a new product architecture (Fixson, 2006), such as increased commonality (Thyssen et al., 2006, Park and Simpson, 2008) or platform introductions (Krishnan and Gupta, 2001) that largely affect firms' cost structures. Product concepts' evaluations, therefore, call for economic analyses, but there is still little guidance and discussion to efficiently support managers' selection of potential NPD projects.

This paper proposes a framework supporting product concept generation and evaluation by providing an accessible conceptualization. Specifically, the framework can configure the requirements across product concepts' various domains while tracing their economic consequences. This framework is not merely "yet another framework", since it integrates the Axiomatic Design's (AD) (Suh, 2001) existent theoretical foundations into microeconomic principles (i.e., demand/supply functions, production, and cost theory) (Mertens, 2020). The theoretical integration supports a convenient and common conceptualization of potential NDP projects' requirements. Specifically, the conceptualization accounts for choices made based on requirements of customer needs, product functions, product family design, production technology, suppliers, and their linkages, thereby generating a product concept. Since the framework employs microeconomic principles, the product concept's integration into the expected demand and price provides a basis for detailed cost analyses. Conceptualizations of configurations and their economic consequences can therefore evaluate product concepts. Collectively, the Extended Axiomatic Design (EAD) framework can be a primer for conceptualization during product concept generation and evaluation.

We apply this framework to a simplified case of a bottle manufacturer in order to conceptualize four product concepts consisting of customer needs, product functions, potential product family designs, including production technology and supplier selection. Further, we incorporate the expected demand and actual input costs while the EAD thereby supplies an approximation of each product concept's economic consequences. Consequently, we demonstrate that the EAD advances product concept generation through easy conceptualization, including the coverage of the product family design and other requirements across product planning. In addition, it can support the evaluation of more complex cost effects' (Ripperda and Krause, 2017). For example, we find that due to overdesign, an expensive product's costs (i.e., potential premium products) shift to that of lower-cost products (i.e., potential value products) across a product family when the commonality in the product family increases (Krishnan & Gupta, 2001). Finally, managers can make an informed decision about product concepts by considering their economic and engineering selection criteria and then choosing the most profitable NPD project.

2 EXTENDED AXIOMATIC DESIGN FRAMEWORK

2.1 Prior considerations

The AD theory sets out to capture and improve single products' design decisions (Suh, 2001, Kulak et al., 2010, Gonçalves-Coelho and Mourão, 2007) while decomposing the linkages and domains of customer needs (CN), functional requirements (FR), design parameters (DP) and process variables (PV).

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The theory of engineering design helps designers map the "what" to the "how" efficiently (Suh, 2001). Using the independence and information axioms, designers can identify the best designs. Although these principles can lead to single products' superior designs, to our knowledge, it still does not signal the resulting economic consequences or superiority designs across product families.
Microeconomic principles frame efficient decision-making with the objective of profit-maximization. Decisions should therefore improve financial objectives that compel managers to rank and analytically weigh solutions (Demski, 2008). Such decisions include not only pricing and product-based capacity planning but also the selection of NPD projects, product (platform) introductions, or eliminations and substitutions. For example, cost reductions frequently motivate decisions on increasing commonality in product design. Collectively, a large set of design decisions requires economic analysis to ensure the best decisions.
The Extended Axiomatic Design (EAD) is a means to integrate engineering design principles into the AD through microeconomics, formalizing the product concept generation and linking it to economic consequences (Mertens, 2020). The EAD's product concept generation supports the incorporation of many potential choices regarding requirements in different domains. In particular, choices can be conceptualized by determining sets of customers $\{C\}$, customer needs $\{CN\}$, products $\{P\}$, functional requirements $\{FR\}$, components $\{CM\}$, activity variables $\{AV\}$, resource consumptions $\{RC\}$, and, finally suppliers $\{S\}$. While each choice predetermines a specific requirement, it is necessary to map how the following domains satisfy these requirements (i.e., how to produce the necessary components, *CM* by *AV*).
To formalize the conceptual mapping between requirements, we have the following example: assume the "what" domain Y is a set of $\{Y\}$ (e.g., $\{CM\}$). The "how" co-domain X is a set of $\{X\}$ (e.g., $\{AV\}$) and can provide the requirements for Y. In other words, X determines the "how" to the "what" of Y. Next, there is the need to map both with each other by a design matrix *A_YX* (i.e., *A_CMAV*). Each row and column of the design matrix must contain at least one non-zero entry, otherwise, there is no relation between them. Equation (1) exemplifies the structure during each entry A_{ij} of the *A_XY* determines what Y requires from X.

$$\{Y\} = [A\_XY]\{X\}, \quad A_{ij} = \frac{\partial Y_i}{\partial_{Xj}}. \tag{1}$$

Using EAD product concepts can be very information-intensive and costly to generate, but designers and analysts do not need to implement all requirements and design matrices. All choices regarding the requirements are optional and identical sets of requirements and identity matrices can easily replace these. This allows product concepts to be simpler and more adaptable to specific problems. For example, when discussing new design solutions of the product architecture (i.e., *A_FRCM*, *FR*, *CM*), it is probably unnecessary to entirely conceptualize the firms' production technology. Designers can then easily employ identity matrices with corresponding sets of requirements to save extensive conceptualization of *CN*, *FR*, *CM*, *AV*, *RC*, *S*. Consequently, EAD can be adapted to many issues of designing to prevent dysfunctional choices during product concept generations and evaluation.

2.2 Product concept generation with the EAD

The EAD can support eight domains to attain a full product concept, which conceptualizes all possible design structures and choices in the product and production program. The conceptualization with the EAD pertains to three steps. Step I preliminarily defines the potential number of requirements for each considered domain. For example, how many customers do we want to target? What are our existing components and products? Which suppliers do we select? Or even questions, like how many products do we want to introduce? Step II requires decisions regarding the mappings between concomitant requirements (i.e., what are the functional requirements in terms of components? Or what functions does a product need to satisfy the customer segment?). Step III adds economic information about input resource prices (e.g., material costs, salaries, machines), expected or realized demands, and potential investment costs to enable economic evaluation. The process can lead to a vast number of domains and can get entangled. Thus, it is advisable to apply three subcategories (i.e., product portfolio definition, product family design, and production technology) that facilitate the generation of elements for product concepts.

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I) Product portfolio definition. Customers (*C*) can be viewed as customer segments, each of which contains a specific set of customers' needs (*CN*) and demand (*q*). The {*CN*} have to be aligned with the functional requirements {*FR*} (e.g., attributes, metrics, and specifications). There has to be a corresponding set of *FR* manifested in a product (*P*) if it has to address a *C*. Finally, the design matrix *A_CNFR* links "what" is needed (i.e., targeting customers) to "how" to achieve it (i.e., in respect of specific functions). Collectively, the product portfolio definition maps the external view of the market *C*(*CN*) with the entry of the internal view of the firm *P*(*FR*).
II) Product family design. Each *P*(*FR*) requires an engineering design in which the framework employs components (*CM*) that can be either physical or non-physical. Each *FR* calls for a set of components (*CM*) that, in turn, satisfies a detailed set of design parameters (Salvador, 2007) comparable to the AD. Since product concepts are not strictly part of technical feasibility checks, the framework restricts the view on design parameters to focus on *CM*. Finally, the design matrix *A_FRCM* between {*FR*} and {*CM*} conceptualize the product architecture (Ulrich, 1995).
III) Production technology. Thereafter, each CM calls for a set of activities (i.e., processes) in the design matrix, which in turn demand the relevant resources (*RC*) (*A_AVRC*). The multiplication of the demand (*q*) and all the design matrices results in a total resource demand that needs to be ordered from suppliers *A_RCS*.
Consequently, the EAD domains are linked via six design matrices (e.g., *A_CCN*, *A_CNFR*, *A_FRCM*, *A_CMAV*, *A_AVRC*, and *A_RCS*), which can formalize customers' preferences into functions and allows designing resource demands without violating axioms or any theoretical assumptions. The eighth domain describes each product by functional requirements *P*(*FR*) and provides an overview of the product family architecture.

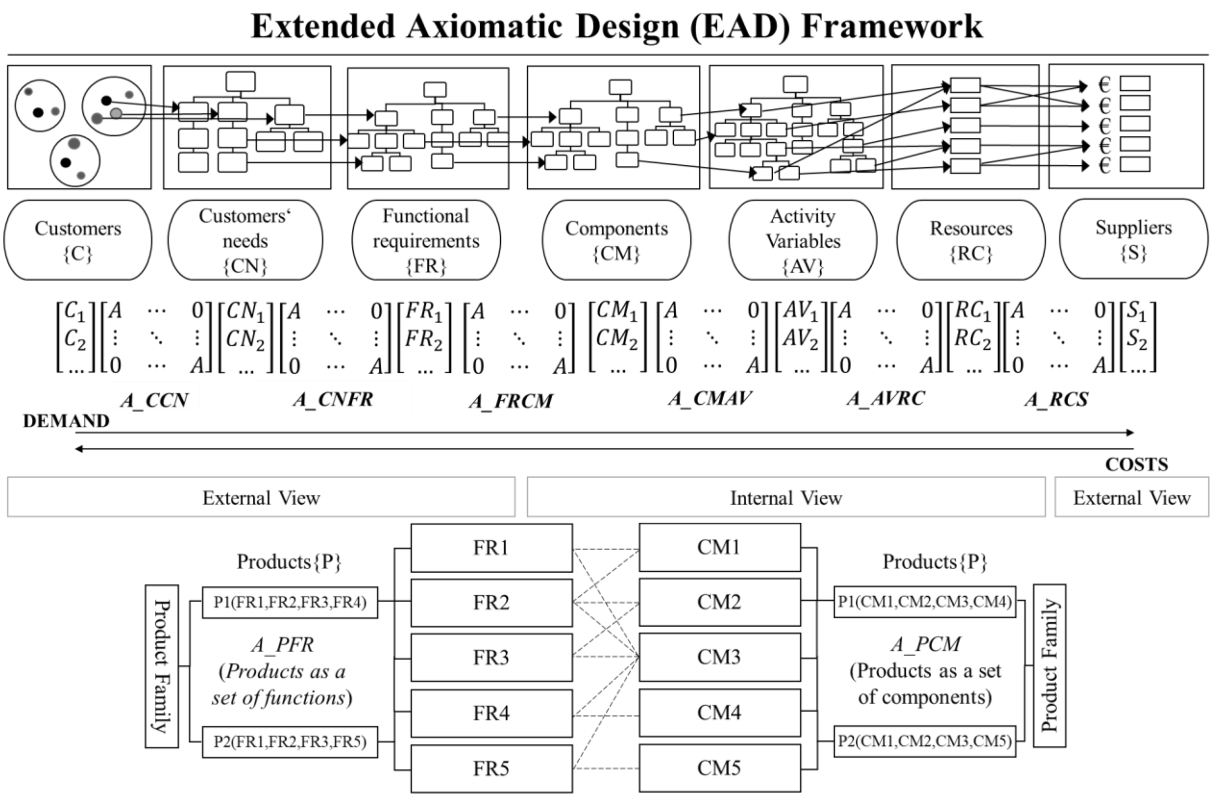

Figure 1. Extended Axiomatic Design and its design matrices. Below, the structure of a product family architecture (PFA) is illustrated.

2.3 Distinctions from AD

The EAD is unique since it differs from the AD in two ways, which is where its novelty lies. Firstly, it employs both a design perspective [A_{ij}=1 if $A_{ij} \neq 0$ or $A_{ij} = 0$] and a demand perspective [$A_{ij} > 0$ or $A_{ij} = 0$]. Similarly, while the demand perspective reflects design structure modeling (DSM) (Eppinger and Browning, 2012) to some degree and prescribes how X leads to Y, the design perspective describes the linkage between two domains that the AD derived. For example, the demand perspective

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strongly influences *A_CMAV*, *A_AVRC*, and *A_RCS*, because their quantities are required to produce units.

This modelling is essential to capture microeconomic principles that specify the costs as the sum of the resources multiplied by the input prices or demand as a function of supply. Specifically, the supplier's resource costs are traceable to earlier domains *CM*, *FR*, *P*, *CN*, *C*. In contrast, the design perspective has advantages in the product family architecture's (PFA) design *A_FRCM*, such as applying the Independence Axiom. Together, these perspectives inform the products' quantities, costs (demand perspective), as well as design (design perspective).

Secondly, the EAD takes a product family view of product architecture as resembling a PFA in the design matrix *A_FRCM*. A PFA describes the mapping of components (*CM*) to the functional requirements (*FR*) of all the products in the product family (Du et al., 2001). For instance, several products only differ in terms of certain functions but have a large common core of functions (Erens and Verhulst, 1997). Each product, however, must consist of at least one distinctive *CM* or *FR* to be unique (Du et al., 2001). The EAD, therefore, goes beyond a single product design and can be viewed as a means to compose individual products' architectures into a more aggregated PFA.

3 PRODUCT CONCEPT GENERATION: BOTTLE MANUFACTURER

A bottle manufacturer plans to enter the reusable plastic bottle market. Its marketing and development department limited the potential product ideas to two products (Figure 2) - a 1L bottle with a narrow opening (Figure 2, left) and a 1L bottle with a wide opening (Figure 2, right).

Both bottles have a similar design, consisting of a body shell, lid, lid connector, and measuring scale, and thus differ only in one function, that either allows for easier drinking (P1) or easier re-filling (P2).

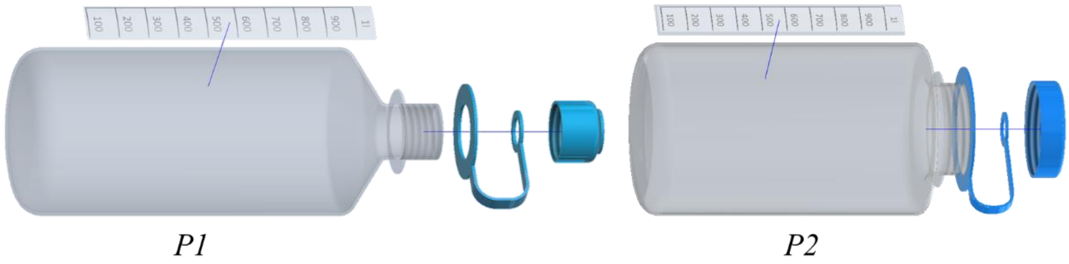

Figure 2. Conceptual design of the bottles

3.1 Product portfolio definition

The product portfolio definition arranges customer segments (*C*) with the corresponding product variants (*P*) and demand (*q*). In our simplified case, the product family covers two customer segments (*C1* and *C2*) Figure 3. For simplicity, *C1* and *C2* correspond to products *P1* and *P2* respectively, while *C1* enquires about the common design, *C2* is an expected new *C* for a wide opening bottle *P2*. Next, the managers use historical information or conjoint analyses to determine each *C* as a set of *CN*. *A_CCN* thereby prescribes the arrangement between customers and their needs (*CN*). Similarly, products consist of functions (*A_PFR*), where each product has several *FR*.

Collectively, the market outlines several customer segments *C* with customer needs (*CN*), while the firm offers several products *P* with functional requirements (*FR*), where the arrangement (*A_CNFR*) between the *CN* with *FR* indicates the fit. In our case, *P1* and *P2* share *CN1*, but differ in *CN2* and *CN3*. *CN2* requires 'no spilling', where *FR5* offers a suitable narrower opening. Likewise, *CN3* calls for 'easy handling', where *FR4* offers a suitable 'wide opening' (see Figure 2 for all requirements and arrangements selected). Finally, the expected annual demand for *P1* is q_1=35,000, and for *P2* q_2=65,000. Both can be sold for €4,50 per unit.

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		C1 (Narrow opening bottle)	C2 (Wide opening bottle)	FR1 (Plastic bottle that provides water for a half day)	FR2 (Good gripping and standing diameter)	FR3 (Easy to open/close lid)	FR4 (Wide opening for easy filling)	FR5 (Narrow opening for easy drinking)	FR6 (Loss-prevention system)	FR7 (Suitable packaging 1L)	FR8 (Readable scale 1L)
Half day hydration functional bottle	CN1	1	1	1	1	1			1	1	1
No spilling	CN2	1						1			
Easy handling	CN3		1				1				
DEMAND	P1	65,000		1	1	1		1	1	1	1
	P2		35,000	1	1	1	1		1	1	1

Figure 3. Product family architecture (PFA) A_FRCM with adjacency matrix to describe the product portfolio constraints.

3.2 Product family architecture (PFA)

Once the *FR* have been determined, they need to be linked to their components (*CM*). Literature offers a variety of techniques for mapping the design between *FR* and *CM*. For example, zigzagging is a typical method where domains (e.g., *FR* and *CM*) are continuously decomposed into hierarchies with greater granularity (Suh, 2001). Regardless of the process, the EAD captures the *FR* and *CM* and conceptualizes a product family architecture (PFA) through the design matrix *A_FRCM*. The resulting product family architecture designates all potential linkages between *FR* and *CM* according to the explanation in §2.2. Notably, the PFA initially shows the extent to which new product concepts can manipulate *A_FRCM*, therefore delineating the design choices made in respect of the components.

In the case of the simplified bottle manufacturer, six components can fulfil all eight *FR* (see Figure 4. Product family architecture (PFA) A_FRCM with adjacency matrix to describe the product portfolio constraints).

Specifically, we see one-to-one mapping in respect of two components, while the remaining have many-to-many mappings. Following the Independence Axiom (Suh, 2001), we conclude that redundancies in the PFA describe non-value-added costs that may need closer examination. An auxiliary adjacency matrix illustrates the interconnectedness of these components. That is, *CM1* and *CM2*, as well as *CM3* and *CM4*, are variety counterparts and thus connected via an XOR connection. The *A_PCM* matrix mirrors this relationship and highlights distinctive and common *CM*. Collectively, the PFA translates the external product view (i.e., products as a set of functions *P*(*FR*)) into the internal view (i.e., products as a set of components, *P(CM)*).

		CM1 (1L container narrow opening)	CM2 (1L container wide opening)	CM3 (Narrow lid)	CM4 (Wide lid)	CM5 (1L packaging box)	CM6 (Short scale-sticker)
Plastic bottle that provides water for a half day	FR1	1	1				
Good gripping and standing diameter	FR2	1	1				
Easy to open/close lid	FR3			1	1		
Wide opening for easy filling	FR4		1		1		
Narrow opening for easy drinking	FR5	1		1			
Loss-prevention system	FR6			1	1		
Suitable packaging 1L	FR7					1	
Readable scale 1L	FR8						1
Products	P1	1		1		1	1
	P2		1		1	1	1

	CM1	CM2	CM3	CM4	CM5	CM6
CM1		X	A			
CM2	X			A		
CM3	A			X		
CM4		A	X			
CM5						
CM6						

X = XOR connection
A = AND connection

Figure 4. Product family architecture (PFA) A_FRCM with adjacency matrix to describe the product portfolio constraints.

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3.3 Production technology

From the PFA, the firm can generate a conceptual design for the production technology. Since bottles share components (e.g., measuring scale, packaging), they also share activities (e.g., package preparation or bottle assembly) and resources (e.g., human workforce). In contrast, products' unique components (Du et al., 2001) lead to specific activities and resources. Overall, the component activities' requirements can determine *AV* (*A_CMAV*) and the resources *RC* (*A_AVRC*), so that costs can be traced to products based on their consumption of *CM*, *AV*, and *RC* (Figure 5). The costs of the consumed resources are either due to own consumption (e.g., development activities, human resources) or are based on supplier prices (e.g., purchased materials), which the resource-supplier matrix (*A_RCS*) provides.

		CM1 (1L container narrow opening)	CM2 (1L container wide opening)	CM3 (Narrow lid)	CM4 (Wide lid)	CM5 (1L packaging box)	CM6 (Short scale-sticker)	RC1 (Plastic material for bottles)	RC2 (Lid - wide)	RC3 (Lid - narrow)	RC4 (Lid-Connector long)	RC5 (Lid-Connector short)	RC6 (Scale-sticker)	RC7 (Cardbord material)	RC8 (Human workforce)	RC9 (Bottle machinery)	RC10 (Development of 1L wide bottle)	RC11 (Development of 2L wide bottle)
Pour plastic into shape (1L wide)	AV1		1					10							3	2		
Pour plastic into shape (1L narrow)	AV2	1						10							3	3		
Lid-pre-assembly wide	AV3				1				1		1				3			
Lid-pre-assembly narrow	AV4			1						1		1			2			
Bottle assembly-finalization	AV5	1	1	1	1	1	1								5			
Package preparation short	AV6					1								5	2			
Scale preparation	AV7						1						1		1			
Development 1L wide bottle	AV8		1														1	
Development 1L narrow bottle	AV9	1																1
Products	P1	1		1		1	1	0.02 €	0.01 €	0.01 €	0.01 €	0.01 €	0.01 €	0.01 €	0.10 €	0.05 €	150,000 €	100,000 €
	P2		1		1	1	1											
Plastic material supplier	S1							1										
Lid part supplier	S2								1	1	1							
Packaging supplier	S3											1	1	1				
Own resources	S4														1	1	1	1

Figure 5. Production technology with the design matrices of A_PCM, A_CMAV, A_AVRC, and A_RCS

Using the EAD, we conceptualize two product concepts of our simplified bottle manufacturer. Yet, there is no restriction on product concepts or on iteratively trying different configurations. For example, the product concepts are not mutually exclusive, and each product concept can be independently forwarded to the NPD. Other configurations could however need more common components or processes in the design. Consequently, the EAD facilitates product concepts' generation from an accessible conceptualization theory that also supplies detailed evaluations based on engineering and economic criteria.

3.4 Product concept evaluation

Each product concept requires an evaluation to support the accurate selection choices of potential NPD projects. While using the EAD, we can apply commonality and modularity indices (Thevenot and Simpson, 2006) and design axioms to the concept based on engineering design theory. Microeconomic principles and information about expected demands, input prices, and selling prices give us future insight into cost effects, contribution margins, and potential market development. More precisely, the EAD allows us to approximate the full manufacturing costs for each product and component, even giving us the costs of functional requirements. Collectively, the EAD's product concept evaluation allows the computation of various engineering and economic criteria, while supporting the most profitable product concept choices. Additionally, unlike prior similar approaches (e.g., target costing, or quality function deployment), the EAD can capture the cost effects of different product family architectures.

Table 1 shows the four product concepts based on the previous conceptualization, which should be used to select the most profitable concept for the subsequent NPD process. As mentioned above, the two product concepts could be developed individually, thereby resulting in two product concepts. Managers are therefore compelled to select either concept A (i.e., only *P1*), concept B (i.e., only *P2*),

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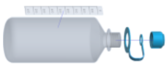
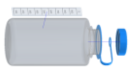
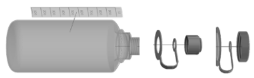
or concept C (i.e., both *P1* and P2). Considering Table 1, the intuitive choice is to eliminate *P1* as an NPD project, because it has a negative contribution margin. By contrast, *P2* shows a positive contribution margin and high profit. Concept C has a smaller profit but could influence the choice with its higher turnover and significant market penetration. Under these criteria, product portfolio managers would probably prefer to select concept B but could ask for improvements of concept C.
Designers could suggest changing the design of the 1L container to modify the wide and the narrow lid with one new component. A potential design concept could be created through overdesign, which would increase the commonality by adding a new component. In doing so, we adjust the desired opening diameter of both lids and use a standardized, new container for both products, which combines the previous components *CM1* and *CM2*. The new component results in a new configuration and yields a new product concept, which is labelled as D (i.e., *P1** and *P2** with overdesigned container). Thereafter, concept D results in a positive profit, even though the input and development costs of the adjustable lids increased. The concept is also highly flexible, as the common component reduces the bottle production's individual procurement process.

Table 1. Product concept evaluations

	Concept A (only *P1*)	Concept B (only *P2*)	Concept C (*P1* and *P2*)		Concept D (*P1** and *P2**)	
						
Development costs	€100,000	€150,000	€100,000	€150,000	€100,000	€150,000
					€10,000	
Quantity per year	35,000	65,000	35,000	65,000	35,000	65,000
Selling price	€4.50	€4.50	€4.50	€4.50	€4.50	€4.50
Commonality index	0	0	0.33	0.33	0.5	0.5
Variable costs	€1.80	€1.80	€1.80	€1.80	€1,71	€1.71
Year 1						
Total production costs	€163,035	€267,065	€162,024	€268,075	€154,762	€276,038
Product costs	€4.66	€4.11	€4.63	€4.12	€4.42	€4.25
Margin	€-0.16	€0.39	€-0.13	€0.38	€0.08 €	€0.25
Profit	€-5,535	€25,435	€-4,524	€24,424	€2,738 €	€16,462
∑ Sum	**€-5,535**	**€25,435**	**€19,900**		**€19,200**	
Year 2						
Total production costs	€63,035	€117,065	€63,035	€117,065	€59,780	€111,020
Product costs	€1.80	€1.80	€1.80	€1.80	€1,71	€1.71
Margin	€2.70	€2.70	€2.70	€2.70	€2.79	€2.79
Profit	€94,465	€175,435	€94,465	€175,435	€97,720	€181,480
∑ Sum	**€88,930**	**€200,87**	**€289,800**		**€298,400**	

At this point, a manager has a choice of four product concepts with distinct engineering and economic consequences. In the first year, the evaluation determines that product concept A is the most profitable. Looking one year ahead, product concept C is more profitable than A or B, but concept D, designed as a result of the two overdesigned bottles (*P1** and *P2**), results in the highest overall profit. Although the development and procurement costs are higher when introducing a standardized 1L container for both products, it also has an increased contribution margin in the second year. In this respect, the EAD's conceptualization gives us an overview of the trade-off between higher development costs of product families and lower variable costs or higher flexibility in future periods (Jiao and Tseng, 1999). Specifically, we demonstrate that increased commonality shifts product costs towards the less demanded product (Krishnan and Gupta, 2001), emphasizing the PFA's role in economic consequences. Collectively, the EAD's evaluations of the product concept can illustrate the product family design's cost effects, which are decisive for optimal selection.

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4 CONCLUSION AND DISCUSSION

It is widely recognized that NPDs in product families are crucial for competitiveness (Brown & Eisenhardt, 1995), providing a large product variety at a reasonable effort and cost (Jiao and Tseng, 1999, Fixson, 2006). However, less literature addresses the cost-based guidance and selection considerations during the early stages of NDP projects' development which impact product concepts' generation and evaluation.

In our study, we propose the EAD framework to support product concepts' generation and evaluation. Using the EAD conceptualization, managers and designers can generate alternative configurations of product concepts before making any commitments. As each conceptualization immediately results in an evaluation by various engineering and economic criteria, it can be viewed as a testbed for product concepts. Furthermore, while each EAD's product concept is based on theoretical principles, conceptualizations should be accessible and easy to communicate between stakeholders. Finally, we believe that product concept generation and evaluation facilitate managers' selection choices of potential NPDs.

In the case of our bottler manufacturer, we illustrate the EAD's advantages. Since the EAD draws attention to the product family architecture (PFA), it is likely to overcome the single product perspective. Product concept evaluations can therefore incorporate the complex cost effects of product families from alternative product architectures (Fixson, 2006). Further, we find that various criteria from the literature can be adopted in the conceptualization to support the selection of product concepts (Moon and Simpson, 2014, Brown and Eisenhardt, 1995). Consequently, managers can make more deliberate choices regarding product concept configuration in the early phases of conceptualization.

Like other studies, we raise several caveats. Using the EAD addresses the product concept development phase, yet cannot support detailed technical analyses or feasibility considerations. For example, the components' need to meet the design parameters (i.e., tolerances or engineering metrics) is neglected as they do not capture all engineering design information. Furthermore, the EAD requires a rich data set of firms to conceptually mirror each product concept. In our study, we are proposing a point of departure of what needs to be collected and how to further facilitate product concept selection. Collectively, the study proposes a framework that can be used as a testbed to generate and evaluate product concepts, while depicting existing product family design which includes economic parameters (Meyer et al., 2019, Meßerschmidt et al., 2020).

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