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Determination of the right level of detail: A methodical approach for life cycle costing integration in product development

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Abstract

In Life cycle costing the processing of the high amount of cost data is challenging for industrial companies. Depending on the existing product and business model the cost structure and the relevance of different cost types differs. To minimize the effort for data processing in product development, this paper presents a methodical approach to determine the needed level of detail concerning the consideration of life cycle cost. The necessary level of detail for business models can be defined by converting the existing cost data into a holistic cost model. The methodical approach presented is applied to an exemplary business model.

Keywords: product development; life cycle costing; business model; cost model

1. Introduction

Cost Driver Analysis in *Life Cycle Costing Models* refers to the systematic evaluation of the parameters that influence the life cycle cost throughout the entire life cycle of a business model. That includes the product itself and services, from the development to the recycling life cycle phase. This analysis is integral to *Life Cycle Costing* (LCC) models, which aim to provide a comprehensive overview of all costs associated with an asset, facilitating informed financial decision-making. By identifying cost drivers, organizations can uncover cost-saving opportunities, enhance resource allocation, and improve overall profitability [1]. In this context, cost drivers are considered as factors that directly influence expenses. The importance of cost driver analysis resides in its capacity to inform strategic planning across diverse sectors, such as manufacturing, procurement, and engineering.

By understanding the relationships between activities and expenses, the industry can optimize its pricing strategies, improve operational efficiency, and strengthen long-term sustainability goals [2]. Despite its advantages, cost driver analysis faces challenges, including the complexity of accurately identifying and measuring cost drivers, which can vary with external factors such as market conditions and regulatory changes. This unpredictability can lead to unexpected cost fluctuations, complicating financial forecasting and resource management for organizations. In addition, the resource-intensive nature of *cost driver analysis* may deter smaller companies from its implementation [3].

The objective of this publication is to reduce the resources required for the analysis of cost drivers in product development through the implementation of a methodical approach. This approach facilitates the development of cost-effective products through the efficient preparation and utilization of data.

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2. Related work

The following section presents an overview of relevant literature on the topics of business model-related life cycle costing in product development, and the role of cost driver analysis.

2.1. Life Cycle Costing

Life Cycle Costing (LCC) is a comprehensive accounting method used to determine the costs of products, assets or services along their lifecycle [4]. It includes *initial costs*, *operating* and *maintenance costs* as well as *end-of-life costs*. Therefore, the integration of life cycle costing (LCC) into the business model and business tactics is of particular significance. In order to facilitate well-founded decision-making all relevant costs need to be considered. Depending on the business model the accessibility of cost data within the product development process differs. For this reason the scope of the life cycle costing approaches applied varies by the operator and given requirements [5].

Life Cycle Costing aims to provide a more accurate understanding of an asset's true cost and to support more informed financial decision-making. Its development and acceptance arise from the understanding that, in investment evaluations, excessive emphasis is often placed on initial costs or market prices, which may represent only a small fraction of the overall costs. In many circumstances, *operating*, *maintenance*, and *end-of-life costs* will constitute the largest share of the total costs incurred [6]. Since LCC encompasses long-term costs, identifying all the costs, estimating them, and accounting for the uncertainties surrounding them is challenging for industrial companies [6]. A universally accepted methodical framework for conducting *Life Cycle Costing* does currently not exist.

Instead, there are industry-specific standards such as ISO 15663 or IEC 60300-3-3. The IEC 60300-3-3 standard provides an application guide for evaluating the reliability and life cycle costs of products. The life cycle costs are represented in a cost breakdown structure, which takes the form of a cube that categorizes the life cycle costs according to three levels [7]. Along with a variety of industry specific standards, researcher-created LCC methods are existing [8]. Examples include life cycle costing approaches for Product-Service Systems provided by Johannknecht et. al. [9].

This reflects a consistent theme throughout the history of LCC approaches tend to be tailored to specific sectors, cases, or questions. Sherif and Kolarik noted this pattern in 1981, concluding that LCC had evolved through applications rather than theoretical models [10]. Over twenty-five years later in 2008 Korpi and Ala-Risku observed that this situation had largely remained the same [11].

2.2. Cost driver analysis

In the literature, there is no standard approach for analyzing and identifying *cost drivers* or *cost-intensive processes* of a business model across the entire product lifecycle. In particular, users applicability and visual support during the analysis are not efficient and supported.

Waghmode et al. and Yongqian et al. provide a methodical approach based on *Activity-Based Costing* to determine potential lifecycle costs [12,13]. In both approaches, cost drivers are specified. Yongqian et al. use the identified cost drivers only as input to calculate direct and indirect manufacturing costs using *Activity-Based Costing* and *Bill of Material* data [13]. Waghmode et al. consider all lifecycle phases and lifecycle phase-specific costs, where relevant cost drivers are assigned to lifecycle phase-specific processes [12]. However, the identification of cost-intensive lifecycle phases is not adequately supported.

Farsi et al. present a framework for estimating lifecycle costs based on a collection of existing cost data for the entire lifecycle. Cost drivers and cost-driving processes are also integrated in this approach. Nevertheless, also here the identification of individual cost drivers is not adequately supported [14].

Ripperda analyzes and identifies previously recorded costs using the Pareto principle. The aim is to reduce the effort of subsequent cost analysis while maintaining high accuracy in cost forecasting by focusing only on the most cost-intensive cost items [15]. Although cost-intensive processes can be identified in this way, cost-intensive lifecycle phases or product architecture assemblies cannot be analyzed efficiently in the early phases of product development.

In general, there is no unified methodical approach, including visual support for the user, that efficiently supports the identification of relevant and driving cost types across the entire product lifecycle and product architecture for different business models.

3. Methodical approach

In section 2, it was shown that there is insufficient visual support for users in product development to identify and analyze cost drivers of different business models across all lifecycle phases. To address this gap, the methodical approach depicted in Figure 1 was developed. This approach is designed to support the identification of cost drivers within the product development process. By using the methodical approach users can reduce the amount of data required for consideration in the Life Cycle Cost model. The methodical approach is fundamentally divided into *Cost Structure Identification* and *Cost Structure Analysis*. The steps in the *Cost Structure Identification* phase assist in creating the cost model and the *Life Cycle Cost Cube*. The *Cost Structure Analysis* supports the analysis and identification of the business model's cost drivers based on the cube.

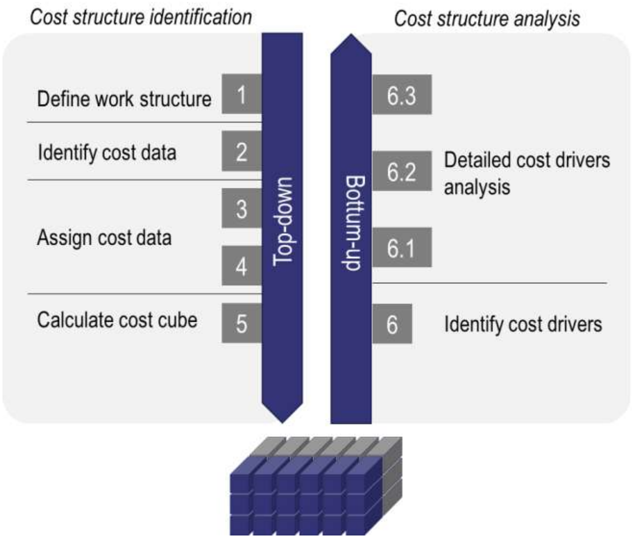

Fig. 1 Methodical approach

In step 1, the work structure or individual business model, including the associated product architecture, is determined. Depending on the business model and the degree of integrated services, the processes to be considered change. In step 2, the cost data occurring in the company under consideration are identified and quantified along the lifecycle. The previously identified cost data are then assigned in step 3 to the lifecycle phases in which the identified cost types occur.

In the developed cost model, a distinction is made between *Investment Costs* and *Process Costs*, which can occur in all lifecycle phases. Depending on the lifecycle phase and cost category, the identified and quantified costs are classified into predefined cost types in step 4. Building on this classification, in step 5, the volumes of the individual cost types are determined. Based on the calculated volumes and the total volume of lifecycle costs, percentage values of cost occurrences are calculated in relation to the lifecycle phases, product architecture, and cost types, and are then visually represented in the lifecycle cost cube.

The lifecycle cost cube, created from step 1 to step 5, serves as input for the subsequent analysis of the established cost structure and the identification of lifecycle cost drivers. Based on the percentage overview in the cube, cost-intensive lifecycle phases, product modules, or cost types can be identified in step 6. In this regard, users can generate more detailed views through cross-sections of the identified cost columns or cost rows in steps 6.1 to 6.3. Depending on the business model or product, detailed views of cost-intensive lifecycle phases, product modules of the architecture, or cost types can be created and used for more in-depth analysis. This ability to create detailed views is intended to enable the user to conduct a more precise analysis of the relevant cost components of the business model under consideration.

3.1. Comprehensive cost model and Life Cycle Cost Types

Throughout the entire lifecycle of a product or a product-service system, different types of costs arise within a company. This work focuses solely on internal company costs that occur during a product lifecycle.

Depending on the product being produced or the level of integrated services, up to comprehensive product-service systems, the cost categories can vary in characteristics and relevance and thus also in quantity of the cost types.

To objectively identify company-specific cost structures and their associated cost drivers, universally valid cost types have been defined across the entire product lifecycle. The defined cost types are presented across the different lifecycle phases in Table 1.

The lifecycle costs are represented over the lifecycle of a product or product-service system. The lifecycle is divided into six phases: Product Development, Procurement, Sales, Production, Use and Recycling. The sequence of the Life Cycle Phases is not fixed and can vary depending on the business strategy of the company under consideration.

Table 1 shows cost types that are universally valid and are intended to provide a framework for categorizing a company-specific cost structure into a generic cost model. The cost types are therefore divided into the two main cost categories I*nvestment Costs* and *Process Costs* across all lifecycle phases. These two main cost categories can be divided into life cycle specific cost subcategories, the cost types.

Here, *Investment Costs* include costs that are predominantly not process-dependent and may include material costs, hardware costs, License costs, or storage costs. To summarize, costs that are not related to personnel processes. In contrast, *Process Costs*, describe the costs that arise from personnel processes and efforts in the respective lifecycle phase. These are, for example, development costs for the respective engineers, documentation costs or maintenance costs during the use phase within a Product-Service System.

The cost types shown in Table 1 are intended to provide a general guideline for systematically categorizing a company-specific cost structure in a superordinate, generic cost model. It should be noted that the cost categories presented in Table 1 provide only a general overview and classification, without claiming completeness. Depending on the company being considered, specific and individual cost types may be added to or omitted from the cost model. The division shown is intended to assist in transferring the individual cost structure into a generic cost model.

Table 1. Life Cycle Cost Types

Life Cycle Phases	**Investment Costs**	**Process Costs**
Product Development	Prototype Cost Hardware Cost License Cost	Research Cost Testing Cost Project Management Cost Design Cost Documentation Cost

		Configuration Management Cost Training Cost Data Management Costs
Procurement	Material Cost Hardware Cost License Cost	Documentation Cost Training Cost Determination cost
Sales	Storage cost Packaging cost	Logistic Cost Documentation Cost Training Cost
Production	Operating Cost Raw Material Cost Energy Cost Logistic Cost Machine Cost Tool Cost Packaging and initial transport Cost Production sample Cost	Production Development Cost Set-Up Cost Production Planning Cost Quality Management Cost Training Cost Documentation Cost Maintenance Cost Assembly Cost
Use	Spare parts cost Storage cost Complaint cost Operating cost Tool cost	Maintenance cost Logistics cost Inspection and maintenance cost Modification and upgrade cost Documentation cost Training cost
End-of-life/Recycling	Tool cost Machine cost	Disposal cost for operating materials Dismantling cost Remediation cost Recycling cost Documentation cost Training cost

4. Application

The following section presents the application of the methodical approach, which is explained step by step using an application example. As part of this study, the cost structure of a coffee machine operated as a product-service system was analyzed using the methodical approach.

4.1. Cost structure identification

Step 1 - Define work structure: In the first step of the methodical approach, the work structure of the cost cube is defined. Therefore, the structure of the product and the underlying business model must be analyzed. An evaluation of the business model of the present application example reveals that it can be classified as a product-service system. Consequently, it is essential to consider the cost of the product over its entire life cycle according to the presented cost model in section 3.1. To analyze the cost drivers of the coffee machine with the product life cycle, the machine is divided into the following three modules: Housing unit, grinding unit and brewing unit. The selected modules for the application example are illustrated in Fig. 2. The structure of the cube is contingent upon the designated work structure and the business model. The level of detail of the analysis can be determined in the initial step based on these two factors. Subsequently, the cost data is allocated to the selected life cycle phases and the work structure.

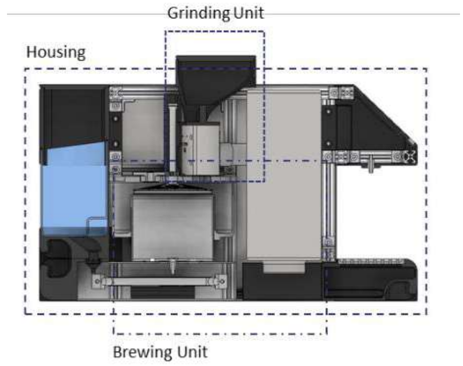

Fig. 2 Modules of the application example

Step 2-5 - Identify and assign cost data: Once the work structure has been defined, it is then necessary to identify and assign the available cost data to the relevant cost types, lifecycle phases and modules. In order to proceed, it is first necessary to define the axes of the cube. The z-axis is defined by the cost model and is divided into investment and operating costs, as well as the previously defined sub-categories. The identified cost types are then allocated to the subordinate cost types. Subsequently, they can be allocated to the lifecycle phases in accordance with the holistic cost model. The selected lifecycle phases constitute the y-axis of the cube. By applying the business model identified for the coffee machine application example, it is possible to identify the relevant lifecycle phases. As the example is defined as a product-service system, all lifecycle phases from development to recycling are relevant for the cost driver analysis. Finally, the cost data must be assigned to the selected work structure. The work structure forms the x-axis of the cube and can be selected by the user. The modules of the coffee machine had been analyzed as part of this study. The allocation of the cost data is attached in the appendix.

4.2. Life cycle cost brick

The efficient identification of cost drivers is the primary aim of the developed methodical approach. In relation to this requirement, an efficient type of visualization had to be implemented. As part of this methodical approach, the cost breakdown structure method according to DIN 60300 is used in an adapted form [7]. The cost drivers are visualized by bars arranged in the form of a cube. Due to the form of presentation, three axes have been adapted for use. The width, height and length of all the bars that results in the full cube are calculated as a percentage of the total costs. For the coffee machine application example, the axes were defined as following. The x-axis is divided into the three modules of the coffee machine *brewing unit, housing unit* and *grinding unit*. The y-axis shows the phases of the product lifecycle product development, procurement, sales, production, use and End-of-life/recycling. The z-axis shows the costs of the modules in the lifecycle phases, divided into investment and operating costs according to the cost model. Once the dimensions of the blocks have been calculated, they can be assembled to form the entire cube. The cube formed for the coffee machine application example can be seen in Fig. 3.

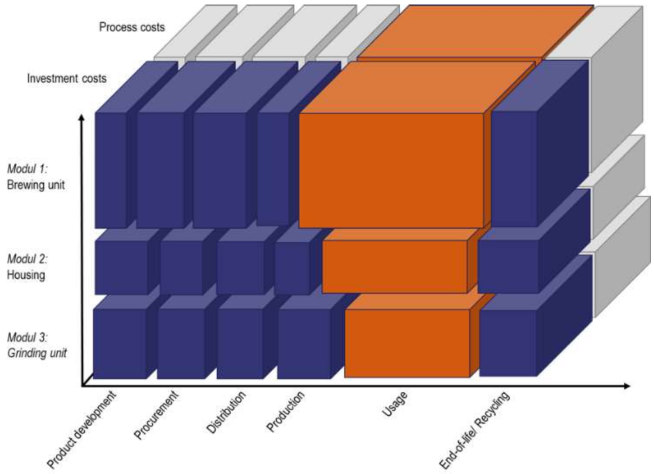

Fig. 3 Cost cube for application example

4.3. Cost structure analysis

Step 6 - Identify cost drivers: Once the cube has been calculated and assembled, the cost drivers are identified in step 6. Three procedures are defined for the analysis of the cube. The procedure is selected at the first level by visual observation of the cube and is based on the largest recognizable cost driver. If the largest cost driver is identified on the y-axis in a product lifecycle phase, step 6.1 is applied. If a cost driver is identified within the work breakdown structure on the x-axis, step 6.2. is applied. In case of a cost type on the z-axis has a high cost share, step 6.3. is followed. The defined procedures serve to identify the largest cost drivers more efficiently. To follow a complete analysis, all three steps should be used to identify all cost drivers. Step 6.1 is carried out as an example for this application example.

For the application example of the coffee machine, the cube formed in Fig. 3 is analyzed. The cost drivers of the coffee machine can be recognized based on the formed cube. The y-axis shows that the usage phase covering 51,83 % of the total cost of all life cycle phases and the brewing unit covering 55,77 % on the x-Axis of the cost of all modules have the biggest cost impact. For the further analysis both categories need to be considered as the cost-intensive factors. Within the application example step 6.1. of the methodical approach is carried out for the usage phase in the following. For further detailed analysis, the cube can be broken down into its subcategories to allow a more detailed cost consideration.

Step 6.1: The first analysis method determines the cost drivers in the lifecycle phases. This method is used if a lifecycle phase could be identified as a cost driver in step 6 of the analysis. This step was also selected for the coffee machine application example, where the usage phase was identified as a cost driver. In the following step, the modules of the coffee machine are analyzed in the usage phase. Where it becomes clear that the brewing unit generates the highest costs covering 64,12 % of the total cost in the usage phase. The cost types of the brewing unit in the usage phase were then compared, with investment costs accounting for the largest share of costs. The subcategories are now considered for further analysis. The subordinate cost types of the investment costs in the usage phase can be identified using the cost model. For the example of the brewing unit, the three cost types operating cost, tool cost and spare part cost need to be considered. The shares of the cost types in the investment costs are visualized in Fig. 4. Based on the analysis, the spare parts cost was identified as the cost driver with the biggest impact of the investment costs. The spare parts cost can be broken down further: as following. The brewing unit module can be broken down into its components. By doing so, the impression cylinder was identified as the biggest cost driver of the spare parts cost.

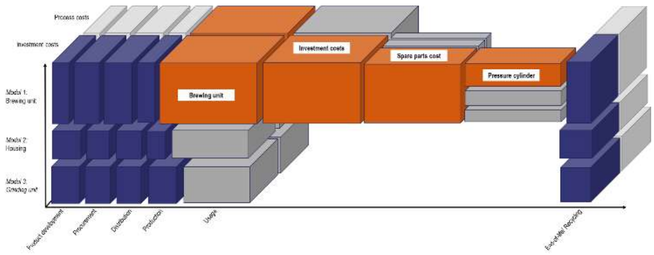

Fig. 4 Cost driver analysis for application example

Step 6.2: The second variant of the detailed analysis is used if a module is analyzed as a cost driver in the first step. For the coffee machine, the brewing unit could be identified as a cost-driving module through the analysis in step 6. For further analysis the lifecycle phases and cost types of the module are analyzed. If a cost-driving lifecycle phase or cost type is recognized at this level, the cube is broken down in the respective direction, as shown in Step 6.1.

Step 6.3: The third step is used if a cost type was identified as a cost driver in the first analysis. For further analysis, the superordinate categories are considered first and then broken down into the subcategories. This analysis is not suitable for analyzing the coffee machine as no cost-driving cost type can be identified in the first analysis. Investment and process costs are almost equally distributed.

5. Discussion and Conclusion

In this research, a methodical approach has been presented to efficiently and visually identify cost drivers within a business model or product. The goal is to focus on cost-intensive processes or materials within the examined business model during lifecycle cost analysis, reducing the analysis effort while maintaining its effectiveness. For this purpose, a methodical approach, including a generic cost model, is introduced in Section 3. The application of the developed approach using the presented example has shown that the methodical approach and the visual representation of the cost model support the identification of cost-intensive life cycle phases, assemblies, and cost types through visual representation and different layers of analysis. This reduces the level of detail required for the analysis of cost drivers, as the visual representation allows for the exclusion of influencing factors from the analysis.

The cost types available within a company may vary depending on the specific product and business model under consideration. In instances where a company's cost types cannot be clearly assigned, there are two possible courses of action. The first is to assign them to the most appropriate existing cost types. The second is to expand the classification system by adding these company-specific cost types. In this case, it needs to be considered that the allocation is made up by individual decisions.

The methodological approach is applicable in a general sense, but is limited in its scope to the identification of costs associated with a given product and business model. The potential influence of other factors has yet to be incorporated into the analysis.

6. Outlook

Due to the large amount of cost data to be considered, future research should focus on the digitization of the methodical approach, including the cost model and the data to be considered. This is the only way to enable efficient applicability in real-world industry settings.

Additionally, there is potential in creating databases related to cost-intensive life phases, assemblies, or cost types of different business models and products. By building these databases, potential cost drivers of various applications could be identified and analyzed early on with minimal effort.

In order to facilitate informed decision-making in product development, the methodological approach developed can be complemented by the incorporation of additional assessment factors. This enables strategic decisions to be augmented with further information, thereby enabling, for instance, the assessment of a product's sustainability or technical value.

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