WHEN COSTS FROM BEING A CONSTRAINT BECOME A DRIVER FOR CONCEPT GENERATION

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Abstract

The ability of addressing global competitive environments is highly determined by quality, costs and time to market. Moreover, focusing on customer is becoming so important that companies have to take into account even the costs that a customer sustain during the product usage, being them extremely important in his purchasing decision. Therefore, manufacturers more and more are forced to reduce not only the costs that directly determine the price of the product, but they must evaluate also those costs that affect the entire lifecycle.

Despite the recognized importance of product lifecycle into literature, none of the present cost estimation methods proposes actual proper solutions. The paper hence suggests a methodology that aim to fill this gap in literature by integrating qualitative information usually available since the beginning of the process with quantitative data derived from lifecycle operations. The proposed method was developed and validated within an automotive company that produce instrumentation for engine development.

Keywords: Design costing, Product Life cycle costing, Early cost estimation

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1 INTRODUCTION

The competition that today's companies are facing is more and more focused on global markets. Consequently, their ability of addressing this global competitive environment is highly determined by quality, cost of products and time to market (Asiedu, 1998). Moreover, companies are required to be flexible in providing product variants, to develop products looking at the entire lifecycle and to deploy these products considering service implications.

Specifically, focus on post-sales and, more generally, on customer is becoming so relevant that companies have to take into account not only the most obvious aspects related to service (e.g., shorter delivery times), but even they must consider costs that a customer sustain during the utilization phase of product life, being them extremely important in their purchasing decision (Shields and Young, 1991). Therefore, manufacturers are forced to reduce not only the costs, which directly will determine the price of the product, but they must evaluate also those costs that impact on users, as well as on society, extending their considerations on all the product life cycle costs. Moreover, this problem of considering product life costs is tangled if one considers that the 70-80% of them are determined by design decisions made at the early stages of development process, while the actual expenses occur mainly during the latter phases, such as production and commercial exploitation (Dowlatshahi, 1992).

Actually, despite the recognized importance of product lifecycle into literature, none of the cost estimation methods proposes actual proper solutions. Methods thought for an early estimation struggle to take into account all the aspects for the entire lifecycle, while the more accurate ones usually used in the detailed design phases, require data that are inaccessible since the beginning of the development process.

The paper hence proposes a methodology that aim to fill this gap in literature by making quantitative information usable since the early stage of product development. This is obtained by a three-step approach that combines case-based reasoning on past designs, with linear regression methods and Activity Based Costing. This integration of qualitative and quantitative evaluations leads to a change in the perspective with which designers look at costs. These last, that are always considered a pure constraint become a driver of design choices and the assessment of different alternatives of cost can lead to generate different design alternatives.

This paper is structured in four sections. Section 2 deals with the relevance of a life cycle approach for companies nowadays and describes the main cost issues during the product development, underlining the importance of early product cost estimation. Section 3 consists of a brief review of the main cost estimation methods in the literature and discusses their weakness in pursuing a whole life cycle cost approach. The remaining two sections are dedicated to the description of the proposed integrated model and its application in an automotive company that develop instrumentation for engine development.

2 BACKGROUNDS

2.1 Life Cycle Engineering

Applying the life cycle concept to product design is a useful approach in order to attempt the reduction of design changes, costs and time to market, as well as to improve quality of products (Asiedu, 1998). Product life cycle engineering specifically considers the product not only as a single entity, but also as a part of a more complex system, made by those processes that refer to the product, beyond design and production, and that must be engineered and made operative (Blanchard, 1979).

Other processes such as maintenance and support, as well as by retirement and disposal in fact follow product design. In this sense, engineering must work in order to modify product functions and structures, so to obtain the maximum utility at lower costs, in terms of not only product, but also considering service and social costs or the environmental impact. These issues therefore result tackled since the first early stages of product development (Keys, 1990) and the consequent technical design choices take into account simultaneously "the system around the product", step by step in each phase of the development (Fabrycky, 1987).

Product lifecycle is object of three streams of literature: Life Cycle Assessment (LCA), Product lifecycle management (PLM), and Lifecycle Costing (LCC). LCA concentrates on the environmental issues related to the product (ISO, 1997; Benda et al. 1993; Emblemsvåg, 2001). PLM focuses on the use and re-use of the information and knowledge about the product so to support the functional design choices. It, on the one hand, focuses on the increasing opportunity given by the using of IT (Nambisan, 2003); on the other hand, discuss about frameworks by which enhance knowledge management and coordination among the functional areas involved in NPD (Cantamessa et al., 2012). Finally, LCC, as part of a more informed design process, concentrates on product costs that occur through the whole lifecycle (Fabrycky and Blanchard, 2010), considering in particular, four categories (research and development costs, production and construction costs, operation and maintenance costs, and retirement and disposal costs).

2.2 Cost issues in product development

Cost estimation is a key factor in the product development process, and more in general it affects company's performance. Indeed, it is intuitive that inaccuracies in this activity could lead to mistakes in strategy and undesirable consequences into business (e.g. an underestimation of costs leads to financial losses, while an overestimation brings to a wrong target price and hence to lost market opportunities). Costs, in fact, constitute a consequent constraint to design activities and hence failing the estimation means either dictate a too thrifty approach or encourage choices not aligned to the effective resources (e.g. an underestimation implies saving perspective on the material choice, while overestimation leads to wrong make or buy decisions).

Cost considerations are usually involved during the development process in the evaluation of concept feasibility along with other requirements. Hence, the main goal of the development team becomes to design the best product at minimum cost, so to comply the product price definition. The most used approaches for this purpose are Target Costing as well as Activity Based Costing (ABC). The former is the most usual and considers the costs that are driven by production costs per unit. It relates them to the estimated market price and the expected profitability of the new products (Kato, 1993; Ewert and Ernst, 1999). The latter focuses instead on activities and resource usage in the development and production phases. Another approach typically used is the Total Cost of Ownership (TCO), although it is mainly involved in the selection and evaluation of supplier (Bhutta and Huq, 2002), considering the transaction costs that affect purchasing (Lindholm and Suomala, 2004).

Despite the wide discussion of these methodologies in literature, as well as their diffusion among companies, none of them seems to consider the impact of the chosen solution on the overall economic performance of the product. Even less these approaches take into consideration the later phases of a product life cycle (e.g. manufacturing and service), although the majority of costs of a manufactured product are generated in the production/distribution stages. This maybe because traditionally new product development process mainly involves people with technical competencies, and hence they put much more emphasis on the technically innovative contents of the product and on its functional performance (Cavalieri et al., 2004) than on the significance of costs as a strategic driver for the design choices.

Technical design choices and economic or operational issues are tightly connected (Ulrich and Steven, 1998), and designers or product engineers should be more aware of their critical role played in determining the overall product performance. The information coming from manufacturing (e.g. number of assembling stages), as well as from operations (maintenance programs, logistic flows, etc.), affect design choices. In the meanwhile, the related cost information, if available at the beginning of the design phase, can also be used for the assessment in product planning.

Costs that are always considered a pure constraint become a driver of design choices and the evaluation of different alternatives of cost (especially if one takes into account the possibilities derived by costs on the entire life cycle) can lead to asses different design alternatives. Even more, when one considers that immediately define a minimal solution to save money can induce, for instance, design changes later and that the cost of design changes increases the more the product development process is in its advanced stages. Nevertheless, taking into account that saving choices (e.g. for a material) can have expensive consequences at the end of lifecycle (e.g. maintenance) determining at that time higher costs.

Focusing on product lifecycle costs has also a strategic value for business. A chosen design with a higher product unit cost and hence a higher price on the market, but that implies a lower operation, maintenance and disposal cost, could be more desirable for a customer than a competing product with lower initial cost (Alan S. Dunk, 2004), but higher costs during the lifecycle. This suggestion can affect significantly customer's purchasing decision.

These evidences imply moving from a “design-to-cost” toward a “design-for cost” approach, being this latter the conscious use of engineering process information and technologies to reduce the overall life cycle cost (Dean and Unal, 1992). In this sense, hence, LCC as a “systematic analytical process of evaluating various designs or alternative courses of action in relation to their lifecycle impact” (Fabrycky and Blanchard, 1991) is the closer way to apply a design-for-cost approach.

3 METHODS FOR COST ESTIMATION

Many contributions on methods for product cost estimation (PCE) are present in the literature. On the most of the cases, the classification is made by considering a quantitative perspective and, hence, the most usually used methods that are the parametric and engineering detailed ones (Cavalieri et al., 2004; Asiedu, 1998). In some few careful cases, they are distinguished more precisely between qualitative and quantitative methods. Niazi et al. (2006), for instance, as shown in figure 1, proposes a hierarchical thorough classification that explores all the possible methodological alternatives.

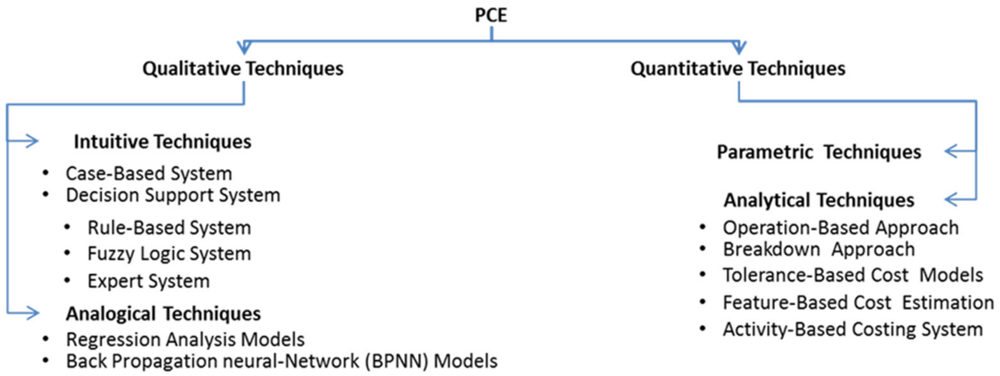


Figure 1. Technique for Product Cost Estimation (Niazi et al., 2006)

The qualitative methods are divided into intuitive and analogical; the quantitative instead are categorized into parametric and analytical. Choosing one method or the other firmly depends by the goals the estimation has and by the decisions to make, as well as by the uncertainty that characterizes these decisions. Therefore, the choice of the method is influenced by the stage of the design process and by the amount and quality of data gathered.

Qualitative cost estimation techniques, in fact, are usually more appropriate in the early stages of design, as they are based on the comparison of the new product with the previous ones. In this case, cost estimation is achieved by making use of historical data, past design experience or manufacturing knowledge. Quantitative techniques instead aim to provide estimations that are more accurate and their usage is often restricted to the final stages of the development process. Here, in fact, detailed information on product’s features, manufacturing and service processes are required for the estimation, as the costs are calculated using parametric or analytical functions, which aim to asses product and process variables as cost drivers.

A typical qualitative method for product planning, for instance, is suggested by Rehman and Guenov (1998) that estimate the cost of a new product extracting its design features from past design descriptions and production knowledge. Being past designs similar, but not equal, for structure and functionalities to the new product, this methodology takes what is useful from more designs and merges it into an approximate concept, on which infer the costs of the new product. Qualitative methods are also useful in order to estimate costs for product industrialization and consequently evaluate the feasibility of different process alternatives. Gayretli and Abdalla (1999) develop, for instance, a rule-based algorithm for the selection and optimization of feasible production processes for components so to derive time and costs of parts features.

The most known and used methods for quantitative analysis are represented by parametric techniques and the activity-based costing (ABC) methodology. Parametric methods look at the cost as function of specific product variables (e.g. geometry, volume, etc.) that drive the economics of a product and its process. These cost drivers are linked to the cost through specific parameters previously derived for each product architecture. Often, parametric techniques are used for estimating production costs so to inform the industrialization phase and support make or buy decisions on machineries and equipment

(Cavalieri et al., 2004). In other cases, these methods are integrated with the information on process (e.g. batch size, number or time of assembling operations, etc.) in order to support the choice of components or materials, when the structure of the product is detailed (Qian and David Ben-Arieh, 2008).
Activity Based Costing similarly supports usually the concept and detailed design activities. This analysis, against the parametrical ones, does not identify cost drivers looking at product features, but instead focuses on the activities and the resources involved in the process. Some applications of these are described in Tornberg et al., 2002 or Park and Simpson, 2005.
Actually, despite the recognized importance of product lifecycle into literature, none of these categories of cost estimation methods propose proper solutions to this issue, as shown in figure 2. This because the methods thought for an early estimation struggle to generate an accurate consideration of all the aspects for the entire lifecycle (Li-hua and Yun-feng, 2004); while the ones used in the more detailed design phases, being more accurate, require data that are unreachable since the beginning of the development (Roztocki and Lascola, 1999). Although, the Life Cycle Costing (LCC) approach (Fabrycky and Blanchard, 1991) seems to aim at methodologically answering to the problem, actually in the literature, there are still no methods able to perform such kind of integration.

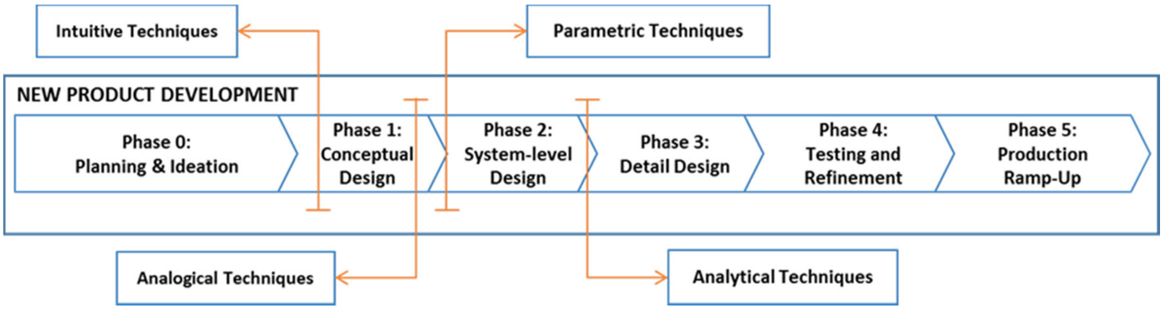


Figure 2. PCE methods and their use in the New Product Development

4 AN INTEGRATED MODEL FOR LIFE CYCLE COSTING

The paper hence proposes a methodology that aims to fill this gap in literature by integrating qualitative information usually available since the beginning of the process with quantitative data derived from lifecycle operations. This integrated information then is made usable since the early stages of product development and is obtained by:

1 a three-step approach that moves through the different aggregation levels of the product tree;
2 the early integration of qualitative and quantitative methods;
3 the integration of product costing methods and process activity costing techniques.

The first step takes into account qualitative methods in order to derive costs at the final product aggregation level. It is based on the data that result from the previous developed products. The second step breaks down the product up to its components in order to estimate their costs, both for materials and for the activities related to the entire product life cycle. While at the first step, the costs estimation is still qualitative, this second step makes use of ABC in order to derive costs of activities and resources, and then linear regression methods in order to extract parametrically the cost drivers of each component. Once the cost drivers and the parameters that link them to the total component cost result, the method can use the same parameters for the cost estimation of each component of the new product. The third and final step, moves back to the product's aggregation level, calculating the total cost in principle as aggregation of the costs of the single components. In the meantime, if the product development process is already proceeded at the detail design phase, the cost estimation can be replaced, at least partially, by the actual data available on the new product (e.g. being the cost of some components known at this point).
These three steps are described in detail in the following while the complete methodological framework is shown in figure 3.

4.1 Step 1

The method starts using a traditional approach that looks at past product designs as draft for the new ones. A case-based reasoning approach is mainly used in order to verify functional similarities between past developed products and the description of the new design problem. The information extracted and made available at this point is related to the type of product, the product segment, its performance and production volume, but also the input and output material, etc. Given the specification for the new product, in fact, the model considers to retrieve the closest matching past product case from the design case base. Once the closest matching has been selected, it is made available to the designer for modifications. Since past product information clearly is already related to its life cycle (as past designs are already on the market), the designer can complete the proxy of the cost by adding ones related to the production (i.e. the number of assembly operation), maintenance, usage and disposal.

4.2 Step 2

The second step focuses on breaking down the product up to the level of components. Case-based reasoning can be used again in order to make the information on the physical attributes (e.g. quantity, geometry, shape, and material) or procurement (make or buy decision) available for the costs estimation of these components.

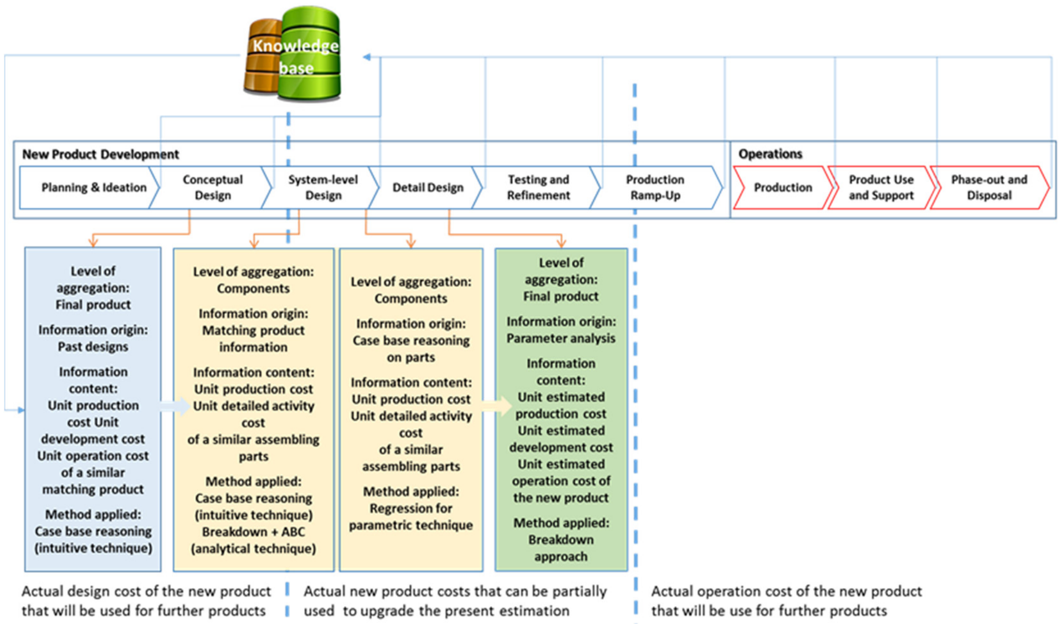


Figure 3. The integrated model for Life Cycle Costing

Besides, Activity Based Costing can be used to estimate the cost of the activities and resources for each component, from the design until the end of the life stage of product life cycle (at least, logistics and after sales). The activity information consists of all required activities consumed by each component. The resource information describes all resources consumed by each activity. All this information together with operational (i.e. working days, hours per day, etc.), and economic (i.e. material cost, labor wage, etc.) data, is used to complete the life cycle cost estimation of each component.

At this point, the data available are still related to past design solutions and hence what is obtained is the whole lifecycle cost of a component belonging to a past product. It obviously can be used as a proxy of a similar component usable for the new product.

Components and activity costs actually can also be used to derive the cost drivers that mainly influences the entire cost of each component. A regression analysis can be useful in order to find out the one-to-one relationships between each of the selected cost drivers, and the cost dependent variable. Once this link is established and the parameters that describe the model are derived, designers can use them for simulations and eventually derive in this way the expected cost of the components of the new product. They in fact, time by time, can link their design alternatives to cost alternatives, by evaluating not only how cost changes if a material changes (think that they are able to do even now), but instead they can assess how choosing a material or a component will change, for instance, the cost of future maintenance (having obviously different materials or components a different service life).

4.3 Step 3

The last step brings the part aggregation level back to the product ones, in order to calculate the overall life cycle cost of the product. The life cycle cost per unit can be calculated by adding all costs and dividing them by the production volume. All the information, on both costs and designs of the new product, will be stored as knowledge useful to feed further cost estimations.

5 THE APPLICATION CASE

The increasing competition that characterizes nowadays the automotive sector, forces firms to improve practices for product cost estimation and to control these costs during the entire product life cycle. The above presented integrated model for life cycle cost estimation therefore has been developed to this purpose at an automotive company that designs, produces and internationally markets measurement devices for engine development.

At the beginning of the project, this company did not have a cost structure dedicated to products. Moreover, the company was not used to detail information on costs, except for the stages of development and production. Therefore, the company's main goal was to provide common knowledge of all the stages involved in the product's life, from their conception to the use by the customers, and to clarify how the costs are linked to each of these phases.

Within the company's portfolio, the model's application was carried out on a specific products family that concerned devices of data acquisition for engine combustion analysis. Three kinds of instruments compose this family of products and the differences among them are mainly due to the set of different product specifications (e.g. analogic input channels, internal high speed memory, and digital input/output channels) and to the type of applications (from the simplest application up to differentiated devices calibrated on different engine sizes). The choice of this family, instead of another, was primarily due to the existence of historical data on costs, since these products were mature on the market. Moreover, the company was planning an upgrade of the product family technology in order to launch a new product version. In this way, the model could have been tested on the new product that would have been developed. As the new product was part of a product family, it would have shared a similar structure, and would have incurred the same set of lifecycle costs, although with a different value.

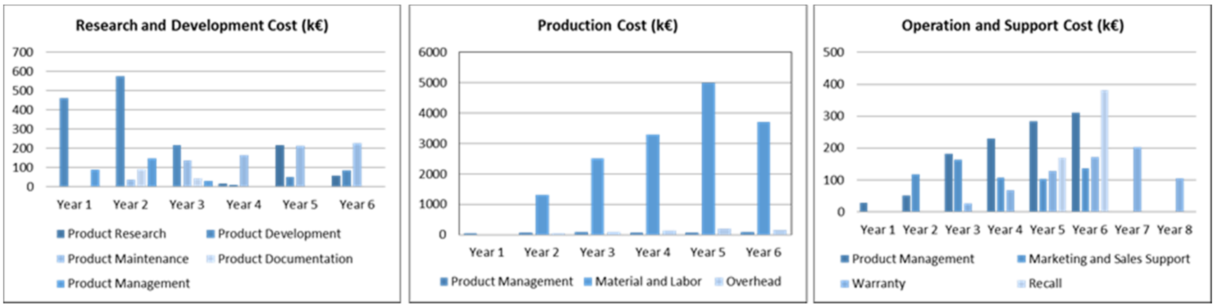
The developed model for product cost analysis was then studied through the company's product life cycle processes (i.e. development, production, sales and customer services stages) and to this purpose, a traditional business process analysis was required during the first months inside the company in order to understand the activities that typically concern the product.

The company operates in order-to-assembly mode: product models are modularly pre-designed and components are assembled once products are sold. Hence, after a preliminary market analysis, the research and further development of the products start. In concurrency, the activities for preparation of the product launch begin (e.g. market testing and preparation of personnel who will be assigned to the control, monitoring and installation of the product). The production will only start when an order is confirmed. During this period, sales activities, order fulfilment and customer service of the product follow one after another. In this last phase, the ownership of the product shift from the company to customers, but these activities too were included in the life cycle consideration for the product analysis.

Once the processes were comprehended, in the first step of the approach the case base reasoning was then applied in order to obtain the product costs and to get the main differences between the old and the new architectures (in term of technological and design data). To this purpose, the development, the procurement and the accounting departments were interviewed, as well as the data base was queried. At the end of this phase, the information on the unit cost (as derived from past products of the family) was then available. It was rough, but already comprehensive of production, sales and maintenance costs.

In the next step, the total product structure was then divided on the next level of aggregation up to the single component. Again, the use of case-based reasoning was fundamental to obtain the

disaggregated structure. To this structure were then associated in detail (activity by activity) for each component the cost drivers (i.e. the activity drivers and resource consumption rates) on its entire life cycle and this was obtained thanks to the application of an ABC method. In particular, the resource consumption and their relative costs were used to derive the cost of the activity for each component. This cost was then subdivided for the number of components at the basis of the activity, in order to derive the unit cost. This cost finally expressed the total amount for each activity for each component.
Figure 4 shows the outputs of the ABC analysis performed and in particular it describes the obtained cost breakdown structure divided in the main categories of research and development cost, production cost, and operation and support cost.



(a) b) (c)

Figure 4. Cost Breakdown Structure for Research and development (a), Production (b), Operation (c)

Figure 4(c), in particular, shows high costs of recall. These are costs for change requests by the customer due to malfunctioning, extra repair and maintenance. These often derive from saving choices in the design phase that impact on the quality and type of components and for that company amount around the 18% of the total company's operating and maintenance costs.
By aggregating these costs that are internal to the company to the ones incurred by the customer for the product usage, it is possible to derive a total product cost profile, as reported in Figure 5 (blue line).

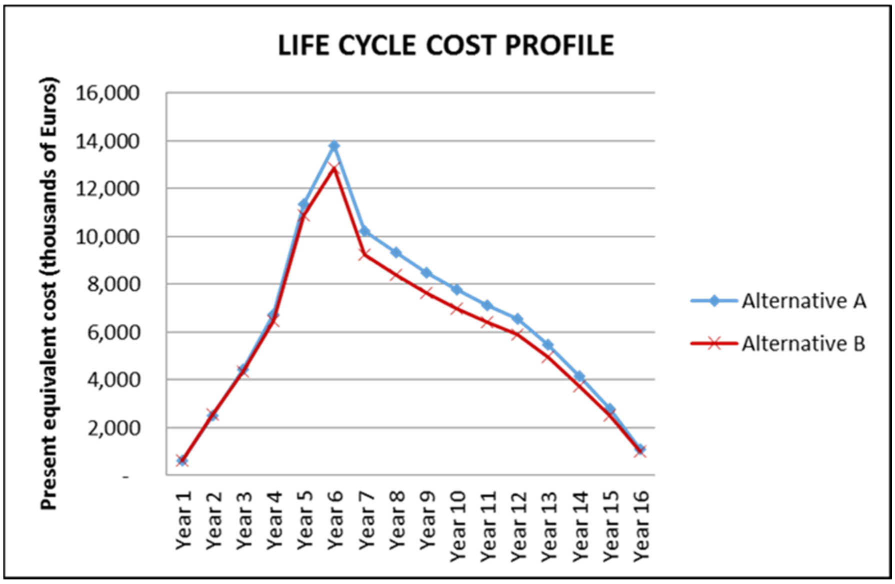


Figure 5. Comparison of two Life cycle cost profiles

This cost profile shows the cost estimation for the future product, reduced to the present equivalent value, as it would have been deigned similarly to the products already produced. This profile can be used either to evaluate the impact of different design alternatives (but still using past data as input) or, with the support of a parametric analysis, to derive the actual costs of the new product once the design choices are made.

In the former case, one can evaluate how the different functional choices create different trends in the overall costs, especially in consideration of the maintenance cost sustained by the customer. Figure 5, for instance, shows the case of a design alternative (red line) that provides an additional function to control the deviation of the measurement respect to the standard one. In this way, the final user can previously understand the maintenance needs, avoiding extra and useless maintenance actions. This obviously affects positively on the total cost profile.

Usually, obtain such level of detail is challenging at the beginning of the design stage, but these are valuable information for the new product, although these do not represent actual costs, but rather a proxy for the cost estimation.

Starting from this output, however, the application of regression analysis can be helpful to derive the main cost drivers and parameters that will affect the actual cost of the new product. A further sensitivity analysis on these parameters allows to understand the main effects of their variations on the total cost profile.

This last part of the analysis, and hence, the third step of the model proposed, is still ongoing within the company. Given the absolute novelty of the method for the company and the natural resistance for the application, the cost framework at the moment is in use only for the family of the product described. However, once the other steps of the approach will be completed and the methodology fully validated, the company aims to extend the method to all the families of products.

6 CONCLUSIONS

Nowadays, purchasing decisions of the most engineering products, particularly the most complex and expensive ones, are not made by customers considering the initial procurement costs but rather on their entire life span costs. Moreover, decisions on costs are made during the early stages of development but these constrain considerably the entire product life and its technical end economic performance.

Techniques for product life cycle cost estimation are increasing in importance in order to help companies to deal with these issues. However, despite their importance in literature, no one of these methodologies, if considered alone, seams to answer properly to an analysis in terms of life cycle. Most of them are used for the cost estimation of a part or component, a special manufacturing process or single segment in the production life cycle. Moreover, quantitative techniques struggle to be used during the first stages of product development and rarely can support product planning phase, although there are made the most strategic decisions and hence at that moment companies might require more precise supports.

The model proposed in this paper is an integrative approach made by three different methods (both qualitative and quantitative), that aims to carry out a complete life cycle cost analysis and estimation, providing enough information since the first early stage of conceptual design. It has been developed for an automotive company that designs, produces and internationally markets measurement devices for engine development.

This integration of qualitative and quantitative methods led some organization consequences within the company. It not only has led to new accounting procedures, but has driven even a change in the perspective with which designers look at costs. These last, which always have been considered a pure constraint, are become a driver of the design choices. This has been the operative support for the company that it has decided to extend it to all the families of products.

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