International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-11 Issue-4, April 2022

A Method for Assessing Economic Feasibility in Mechanical Design

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Abstract*: The careful study of the costs of a preliminary design is fundamental for its realization and future operation. The design of mechanical systems requires innovation, creativity through technological research. The related feasibility studies are full of many parameters, not very effective, and take place in a concurrent and varying environment. It is therefore difficult to conduct them effectively. The costs of the factors of the product life cycle are listed in the literature. These are the costs of design, manufacture, distribution, operation, and recycling. Those intrinsic to the expression of its life cycle costs are identified. This allows structuring an approach of economic estimation of the feasibility. The defined cost indicator allows measuring the feasibility of a design project. This "cost" criterion is the basis for indicating the relevant tools and methods for storing the technical data according to the system requirements and for coordinating the partners in conducting the study.

Keywords: Factors of the Product's Life Cycle, Feasibility Study In Mechanical Design, Intrinsic Costs

I. INTRODUCTION

The competition pushes companies to design and develop their product in increasingly shorter time frames. The feasibility study, located upstream of the design cycle, must therefore be carried out in order to decide on the possibilities of considering an investment [1]. It allows proving, with the help of indicators, that the product is technically feasible and economically profitable. The aim of the feasibility study is to verify that, "theoretically", the technological project is consistent with the company's strategy and resources.

The evaluation of this profitability involves taking into account the intrinsic factors of a product's life cycle. The life cycle of a product can be broken down into eight main phases: expression of the need, research and development of the product, industrialization, certification, manufacturing, distribution, operation, and dismantling [2], [3], [4], [5]. Feasibility studies are carried out throughout the design-realization process: feasibility of principles and processes, the feasibility of industrialization, feasibility of operation, feasibility of recycling, etc.).

The three important phases of a product, which are the "Feasibility, Design and Development Studies", are distinguished by the financial commitments related to the tasks necessary for its execution. Cost estimates must therefore be adapted to these different phases of a project. Techniques for estimating the cost of a product can be qualitative or quantitative [6]. We envisioned summarizing the feasibility of a mechanical design project in five main steps: design, manufacturing distribution, operation, and recycling. Economic feasibility is also omnipresent. A formal feasibility study approach is, therefore necessary to conduct this crucial task. Thus, we will propose in this article an approach to study the project cost at the design stage to validate its feasibility.

II. METHODOLOGY

We present the methodology used to develop the feasibility costing approach. The following Fig. 1 summarizes the methodology in three steps.

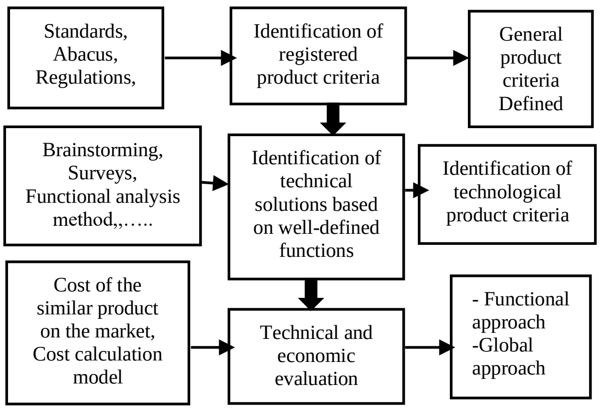

Fig. 1.Analysis Approach For Estimating Economic Feasibility

The design of a standard product must meet normative requirements in order to be approved. The first step in the product feasibility study is to specify all necessary requirements that the product must meet. Several authors have proposed lists of defining specifications for the design phase [7], [8], [9], [10], [11], [12], and [13]. This is an important aspect of the product specification to better guide the choice of technological solutions using conventional design methods.

The third step is to simulate functional costs and propose models for determining overall costs based on intrinsic factors of the product life cycle. It is useful to draw on the costs of similar products on the market. In the study of the feasibility of the product, it is particularly important to be able to start the different activities in a completely parallel way. Then, their progress will eventually be simultaneous or sequential depending on the team's possibilities, the objectives, the tasks to be carried out, the deadlines, etc. We can group together the activities of the definition of the feasibility study.

Manuscript received on December 28, 2021.
Revised Manuscript received on March 17, 2022.
Manuscript published on April 30, 2022.
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(study of the needs, study of the service functions), those of creation and solutions (research of ideas, study, and evaluation of solutions), and those of materialization and validation (definition of the product, mock-up, and prototyping).

III. RESULTS AND DISCUSSION

A. Functional Approach

This step consists in conducting the work allowing to evaluate the solutions of the product feasibility cost. The technical-economic evaluation aims to measure the value of the service functions by comparing the histogram desired in the Functional Specifications and the histogram of the costs of these same functions. Indeed, for each service function, make a list of the components with their costs and build the histogram of the distribution of the costs by function. Among the solutions obtained, we look for the most expensive one and focus on it. We determine the final value of the product and its cost and then we compare the two. The value index is used to compare solutions on the basis of the quality/price ratio. When a function with a given number of components is too expensive, it is necessary to launch an analysis to find the causes and to identify the technical solutions, components, etc. that could be at the origin of this extra cost. Once identified, the technical solutions, components, etc. are replaced by less expensive solutions without changing the function.

B. Global approach

A global approach is to define the feasibility cost indicator of a product design. Let's say the following ratio:

$$I_C = \frac{C_f}{C_t} \qquad (1)$$

With I_C the cost indicator, C_f the final cost, C_t the target cost (similar product on the market, customer requirement).

If $\boldsymbol{I_C} \succ \mathbf{1}$ then the standard product is economically unacceptable and may be acceptable for custom products.

If $\mathbf{0} \prec \boldsymbol{I_C} \leq \mathbf{1}$ then the product is economically acceptable.

It is, therefore, necessary to determine the components of C_f and C_t.

— Determining the final cost C_f

At the feasibility study stage, the costing of the major stages of the product can only be done on the basis of experience to obtain an order of magnitude of the overall cost of the product. We then use the analogical method of cost estimation which consists in estimating the cost of a realization from comparisons with similar finished realizations whose cost is known. This involves a necessarily subjective judgment and assumes that the company keeps a history of all its products. It is a method that can be quick and inexpensive, but, it provides reliable results only if it is applied rigorously. The parametric cost estimation methods that can be used at the "Design" stage must be consistent with the project definition state. We generally rely on the "product concept": we do not know precisely how it will be manufactured but we have a certain number of physical characteristics or parameters, such as mass, volume, energy absorbed, etc., from which we can make estimates (product design). At the development stage, we no longer think in terms of products, but in terms of relatively well-known tasks to be accomplished (product manufacturing). Each activity can therefore be valued separately using analytical methods of cost estimation [14]. In general, the final cost of a product can be given by the formula:

$$C_f = C_{Design} + C_{Manufacturing} + C_{Distribution} + C_{Operating} + C_{Recycling} \qquad (2)$$

This cost represents the cost of all the design activities that will bring out the elements necessary for product development (manufacturing). The ABC (Activity-Based Cost) method is used to evaluate the cost of product design and development activities. According to the definition proposed by the American industrial business cooperative CAM-I (Computer-Aided Manufacturing-International), the ABC method is designed to "measure the costs and performance of activities and cost generating objects (notably products). Costs are assigned to activities based on their resource consumption. Costs are assigned to cost objects based on their use of activities. ABC identifies the causal relationships between cost drivers and activities" [15], [16]. The ABC method recommends estimating the cost of the design via the cost drivers of activities performed. The cost of the design is defined by the activities used and the value of their cost drivers.

$$C_{Design} = \sum_{i=1}^{number\ of\ cost\ center\ used} ACD_i \times ACDR_i \qquad (3)$$

Where ACD is the amount of activity cost driver used. The activity cost driver rate (ACDR) is obtained by dividing the total cost of each activity by the activity cost driver value.

$$ACDR = \frac{\text{Cost of an Activity}}{\text{Activity Cost Driver used}} \qquad (4)$$

The ACDR can be also defined as:

$$ACDR = \frac{\sum_{i=1}^{number\ of\ cost\ center\ used} CCR_i \times CCD_i}{\text{ACD}} \qquad (5)$$

Where CCDi is the amount of center driver i used for the activity, with Cost Center Rate that is

$$CCR = \frac{\text{Annual cost of center}}{\text{Cost Center Drivers spent in 1 year}} \qquad (6)$$

The manufacturing cost ($\mathrm{C_{Manufacturing}}$) is the cost of the different tasks to be done to implement the solution including labor, tools, consumables, etc. Several software programs allow the estimation of the manufacturing cost during the design phase of a product, such as DFMPro, SolidWorks (SolidWorks Costing), Autodesk (Autodesk Simulation DFM), Micro Estimating, Costimator, etc. These software programs use an analogical method to calculate the cost.

The manufacturing cost model ($\mathrm{C_{Manufacturing}}$) of a specific component is composed of the material cost ($\boldsymbol{T_m}$), the process cost ($\boldsymbol{T_i}$) and the surface coating and/or heat treatment cost ($\boldsymbol{T_t}$) [17]:

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$$C_{Fabrication} = T_m + \sum_{i=1}^{n} T_i + T_t \quad (7)$$

The cost of the material is defined by the volume of raw material V_{rm} multiplied by the cost of the material per unit volume $\boldsymbol{C_{mp}}$.

$$T_m = V_{rm} \times C_{mp} \quad (8)$$

The total volume of raw material is easily determined in the case of simple shapes such as bars, sheets, and the like. However, if the total volume of raw material is complex or unknown, then it can be calculated as a finished volume component $\boldsymbol{V_f}$ and a waste coefficient $\boldsymbol{W_c}$, which takes into account the amount of material to be removed and depends on a particular manufacturing process and the complexity of the component shape. Thus, the formula is as follows:

$$V_{rm} = V_f \times W_c \quad (9)$$

$$T_i = P_c \times R_c \quad (10)$$

Where

$R_c = C_c C_{mp} C_s (C_t ou C_f)$ is the relative cost

$C_c = complexity\ factor$

$C_{mp} = material\ factor$

$C_s = \min imum\ \sec tion$

$C_t = tolerance\ factor$ or $C_f = finishing\ factor$

$P_C = process\ cost$

$W_c = waste\ coefficient$

Distribution costs ($\boldsymbol{C_{Distribution}}$) or non-production costs are at the end of the business cycle, in an industrial firm [18]. These costs include:

- Direct labor expenses: salaries of salespeople, representatives, delivery people, salespeople, etc.

- Distribution costs: advertising expenses, packaging costs, transportation costs.

- Indirect expenses: from the "distribution" analysis center charged to the goods or products sold, from the "administration" center, from the "financial management" center

- Other possible incorporable expenses: insurance, intermediary commissions, brokerage fees, after-sales service expenses.

Operating costs ($C_{Operating}$) are the expenses associated with operating a device, component, equipment, or facility. These costs are resources used by the owner of the equipment (device, component, facility, etc.) solely to maintain its existence. They are the recurring, regular, usual costs of operating the equipment. Operating costs may then include Staff salaries, advertising, real estate expenses, including rent payments, office space rental, furniture and equipment, the investment value of funds used to purchase the land, if owned instead of leased, property taxes, operating taxes such as fees charged to carriers for highway use, electricity, fuel, equipment maintenance, telephone, internet, office supplies and consumables, insurance premium, equipment depreciation, damage due to uninsured losses, accident, negligence, ordinary wear and tear, operating taxes, income taxes. Depending on the equipment to be operated, the costs of the above items (not exhaustive) may be fully or partially summed to obtain an estimate of the total cost of operation. The distribution and operating costs are the extrinsic parameters of the equipment. The ease of distribution and operation of equipment depends on intrinsic criteria to be integrated with the design phase of a product. These criteria can be maintainability, ergonomics, disassemblability, etc. These are part of the product requirements that are generally defined in the design cost.

The recycling cost ($C_{Recycling}$) calculation method assumes that each part of the product can be used in several ways [19].

- Disassembled and sold as homogeneous parts,

- Disassembled and sold as a combination of (compatible) components,

- Disassembled and used as waste,

- Disassembled and used as hazardous waste.

In addition, the disassembly of each link, defined as possible to disassemble, is associated with a specific cost in time, labor and tool use chosen by the designer. All of this information is used to create a recycling cost estimate for a given product.

The method takes into account two fundamental factors that affect the cost of recycling: one is the cost of disassembly, and the other is the cost of disposal and recycling of the materials used in the product. The total cost of recycling is the total revenue on materials that can be sold after disassembly, and the cost is the total cost incurred for disassembly, hazardous waste disposal, transportation to landfills.

$$C_{Recycling} = \sum_{i=1}^{n} K_{MD} - \left(\sum_{i=1}^{n} K_{UMN} + \sum_{i=1}^{n} K_{Odpad} + \sum_{i=1}^{n} K_{Dem}\right) \quad (11)$$

Where

$C_{Recycling} = \cos t\ of\ recycling\ the\ product$

$K_{MD} = \cos t\ of\ good\ matrials\ (recyclable\ and\ reusable)$

$K_{UMN} = \cos t\ of\ hazardous\ waste\ treatment$

$K_{Odpad} = \cos t\ of\ waste$

$K_{Dem} = \cos t\ of\ disassembly$

$n = number\ of\ materials\ in\ the\ given\ product$

$$\sum_{i=1}^{n} K_{MD} = weight \times price\_[kg \times unit]$$

$$\sum_{i=1}^{n} K_{UMN} = weight \times price\_[kg \times unit]$$

$$\sum_{i=1}^{n} K_{Odpad} = weight \times price\_[kg \times unit]$$

$$\sum_{i=1}^{n} K_{Dem} = \text{time of disassembly}$$

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— **Determining the target cost** C_t

Whether it is a new product design or a re-design, the target cost is generally given by the customer during the specification of the needs (Customer Requirements Specification). He gives a range in which he would like the cost of his product to fall. In addition to knowing the budget, the designer must know the category of the product (standard product or customized product) and its performance (minimum, average, high, very high). This knowledge allows to orient the definition activities of the feasibility study and also to estimate the target cost based on similar products. The target cost method can be used to determine the $\mathbf{C_t}$. It consists in determining for any product a "target cost" that should not be exceeded due to the price imposed by the market and the expected profit margin defined by the company [20]. The cost is considered by a company as a constraint that must absolutely be met to achieve its objectives. This cost is determined, on the one hand, by the selling price (**PV**) whose level is imposed by the value of the product perceived by the customer, and, on the other hand, by the target margin requirement (**Mc**) generated by the strategic choices of the firm.

From the estimated cost (**Ce**) or pre-established cost evaluated on the basis of the current competencies of the company, generally higher than the target cost, the target cost method highlights and measures the progress requirement (**EP**) consistent with the ambitions and technical possibilities of the company [20].

$$EP = C_e - C_t \qquad (12)$$

With $C_t = PV - M_c$ and the objective is that $EP = 0$

When the estimated cost is higher than the target cost, consequences can be considered: either a modification of the product or its composition (technical modification), or changes in the supply and manufacturing conditions (cost reduction).

C. Synthesis and positioning

Controlling the likely cost of a product at the feasibility stage is a cage of its realization. The life cycle of the product is based on two main aspects. An extrinsic aspect falls to the use of the product especially in its phase of distribution, exploitation, and recycling, and an intrinsic aspect that is preponderant for the quality of the product. This last aspect includes all the phases of the life cycle of the product. Apart from the design phase, there is an intrinsic dimension in the manufacturing, distribution, exploitation, and recycling phases. The quality of manufacturing, distribution, operation, and recycling is decided in the design phase. There is therefore an intrinsic dimension to these extrinsic phases. Cost estimation based on their intrinsic parameters aims to calculate the feasibility cost for the specified criteria in manufacturing, distribution, operation, and recycling of the future product. The literature clearly addresses the estimation of feasibility costs for the design, manufacturing, and possibly recycling phases. However, no literature determines the intrinsic costs related to the distribution and operation phase. The intrinsic feasibility of distribution would thus be related to the ergonomics of the product and that of operation to the maintainability and to the logistic and ergonomic support equipment.

IV. CONCLUSION

The objective of this work was to propose a brief approach to estimate the feasibility cost of a mechanical design project. The formulated cost indicator is decisive for the launching of the project. This indicator is the result of a ratio of the components of the actual cost to the target cost of an existing analogous product. The complexity of the cost components is manifold and requires a careful and plausible approach to their estimation. The intrinsic cost elements of distribution and operation have yet to be clarified. These will be defined as demanding constraints to be integrated into the product.

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