# COST ESTIMATION MODEL FOR EARLY STAGES IN THE MECHATRONIC PRODUCT DESIGN

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*Nowadays, mechatronic systems are present as a solution in many of our everyday products. The importance of innovation and effective product development process is increasing. In the technological context, mechatronic systems have a great influence on a large number of products. The mechatronic products present variety and integrate specific functions to form a system, by making the developing process a complex activity. Adequate models are necessary to manage the complexity of mechatronic products design. These models need support in the early stages because during these many decisions are taken. Cost estimation helps the process of decision taking in relation to economic aspects, providing a product that represents economic benefits to the company and customer.*

*Palavras-chaves: Mechatronic product design, Project cost estimation, Supports methods and techniques*

## 1. Introduction

Actually, world companies compete to satisfy customer needs, developing high quality and low cost products. These products must provide aggregated value and customization capabilities, all integrated to the basic needs of the customers. This leads to an increased development of complex systems, many of them being mechatronic products.

The success of product development process is based in maintaining the cost, time and quality objectives under control, following a plan (EHRLENSPIEL, 2007). The process should be the most efficient, seeking to perform change management in order to achieve the greatest benefits for the stakeholders in the project.

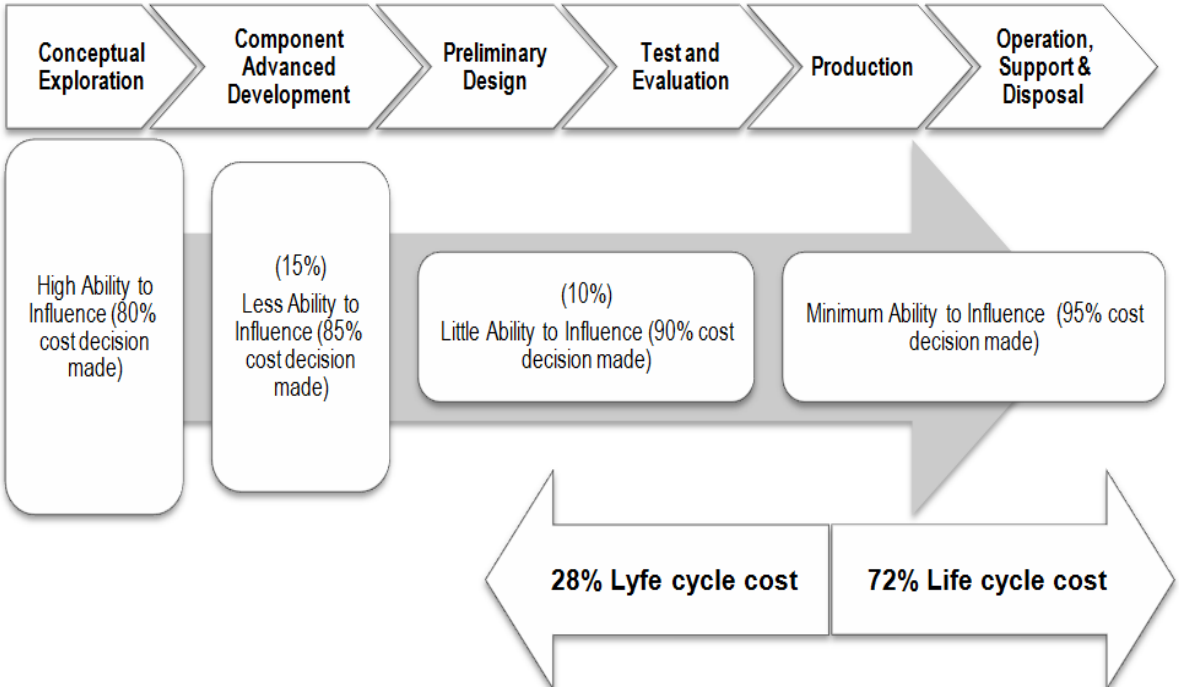
Regarding the economic aspects of product design, only about 60% of new products launched in the market are successful and 45% of the resources allocated for development, do not bring the return of the investment expected. One major cause of failure when launching the product into the market occurs when the cost of products turn to be higher than those initially planned in the early stages of the product design (BRUE; LAUNSBY, 2003). The importance of cost estimation in the early stages of product design is the reduction of costs throughout the entire product lifecycle, providing a differentiated product and an appropriate cost. Cost estimation presents a great challenge on the early stages of product design, because at the beginning there does not exist enough information about product design.

The principal constructive solutions of the product are defined in the early stages of product design. At that moment the materials and technology to be used, the manufacturing process and the final product architecture are determined. The choices taken in the early stages of product design are responsible for 80% of the costs of the final product Farr (2011) and Rozenfeld *et al.*, (2006). In summary, any improvement in the early stages of product design will have a direct impact on product cost. Figure 1 illustrates how the cost of the product is determined by decisions taken during the phase of conceptual design.

The greatest potential for reducing cost of products occurs in the phase of informational and conceptual design. This is exactly when most of the decisions that are significant to determine the final cost of the product are taken; it is the moment in which the highest degree of uncertainty about the product exists (ROZENFELD *et al.*, 2006).

The approach of mechatronics specifically influences the phase of conceptual design because it is during this phase that the majority of decisions regarding the functional interaction and spatial integration of the system design are taken (DE VRIES; BREUNESE, 1995).

Figure 1 - Costs incurred and committed during the product design




Source: Farr (2011)

Even though importance of cost estimation models is well known, there were not found in the literature product design models that emphasize on them or in the organization of their activities. Currently cost estimation is focused on models for costs estimations of software and hardware separately.

Considering the existing gap this work proposed a cost estimation model for the early stages of the mechatronic product design.

The structure of this work first presents the theoretical framework of mechatronic systems, types of mechatronic products, models of mechatronic product design and cost estimation methods. The objective is to identify and select the proper mechatronic product design model for the implementation of the cost estimation process. After that, a description of the proposed model is presented. The process of making decisions based on the cost of mechatronic products design is supported by this model. Finally the conclusions of this work are presented.

## 2. Related works

### 2.1. Mechatronic systems

Regardless of the type of mechatronic system, there is a need to understand the fundamental principles of mechatronic systems before tackling the design process of mechatronic products (VASIĆ; LAZAREVIĆ, 2008). A mechatronic system can be defined as a set of subsystems, hardware and software components, and people designed to perform a set of tasks to satisfy specified functional requirements and constraints (HEHENBERGER *et al.*, 2010).

For a product to be defined as a mechatronic product, it must meet the following criteria (BARBALHO, 2006): integration of the mechanical, electronic and software technologies; the basis product functions are provided by the integration of the technologies that comprise it; and the system can be understood as an open loop or close loop system. The main components of a mechatronic product are: sensors and instruments; processing and control software; actuators and drives; design engineering; and communication systems (BRADLEY *et al.*, 2010).

In this context, mechatronic systems are multidisciplinary; therefore the knowledge required for developing such products/systems is broad. There is a lack of integrated development processes and tools for mechatronic products (HEHENBERGER; ZEMAN, 2007).

Mechatronic products can be classified as follows (RZEVSKI, 2003):

- Automatic mechatronic systems: include the most common mechatronic systems that are capable of handling material and energy; communicate with their environment and present behaviors of self-regulation, ie, pre-programmed response to anticipated changes in their environment;
- Intelligent mechatronic systems: systems capable of achieving goals under conditions of uncertainty. These systems are designed to respond to changes in its operating environment without need to reprogram them. Such systems are developed by using fuzzy logic, neural networks and artificial intelligence;
- Intelligent mechatronic networks: systems able to decide their own behavior by negotiation between its constituent units, each of which is an intelligent mechatronics system.

### 2.2. Mechatronic product design

The development of a mechatronic system is a multidisciplinary challenge. Poor communication between the engineers and designers of each area can lead the company to divide the product into independent parts, causing each part to be optimized individually, leaving aside a global optimization of the product (BUUR; MYRUP, 1989). In addition to this, mechatronic systems are distinguished as complex systems, focusing on the integration of different engineering areas: mechanics, electronics, software and control. The complexity involved in developing mechatronic products, leads to the need for a systematic development process.

Different models designed to support and promote the task systematization of the product design were studied: Back (2008), Rozenfeld *et al.*, (2006), Pahl & Beitz (2005), Pugh (1990), etc. The importance of these models is that they provide methods, techniques and tools to support the product development process. However they are focused on the development of mechanical products.

Different models for the development of mechatronic products are known, featuring the integration of mechanics, electronics and software: 3-cycle model (GAUSEMEIER *et al.*, 2011), axiomatic design (SUH, 1990), V model (VASIĆ; LAZAREVIĆ, 2008) and hierarchical model (HEHENBERGER *et al.*, 2010).

V model stands out among others because it describes the integration of activities and tasks that compose a mechatronic product design. The 3-cycle model includes the V model in its proposal and synchronizes the activities of conceptual design of products and conceptual design of production systems, called integrative conceptual design. This focus on integrative conceptual design is an advantage when compared with the other models that do not have this feature. The decision making process will be based on important aspects or constraints of the manufacturing process at the time of product design. Because of this, 3-cycle model was selected to build the proposed cost estimation model. Nevertheless, these studied models have a gap; they do not approach to the cost estimation process for mechatronic products development.

### 2.3. Cost estimation process

The cost estimation of the product is the process of predicting the necessary effort to develop a product. The estimated product cost allows the company to make strategic decisions and thus establish paths to be followed throughout the product development process (FERREIRA, 2002).

Cost estimation process employs mathematical methods, the key factor when choosing a cost estimation model is the accuracy of their estimates. It is important to highlight that employment of these methods, especially in the phase of conceptual design is a difficult and complex task, because of the high abstraction level of information available.

Cost estimation methods are divided into three categories (FARR, 2011):

- Parametric estimations: are basically mathematical relationships between cost and some parameters related to products and processes. The parametric method is the only mean available when there is not database with enough information. Parametric estimations are constructed using empirical data that take the form of a linear equation multiplied by several factors designed to capture complexity, size and others;
- Analog estimation: is based on historical results from similar products. It requires a broad experience to develop any kind of predictions to determine the appropriate independent and dependent variables. It has the advantage of being faster and simpler than other estimations, but with lower accuracy and being more dependent on people with experience and expertise to compare costs between different projects of the company;
- Detailed Engineering: is a direct estimation that accumulates the estimation for each component or part to project overall cost. This method allows results with some precision by detailing specific "item by item" on one hand, and on the other it can be expensive and time consuming, especially in projects with many complex activities and resources.

The cost estimation process for mechatronic products consists of three levels: hardware, software and integration. Hardware costs of mature technologies are well known e.g. HPT – Hardware Points Technique (MONTEIRO *et al.*, 2009) and the costs of software technologies have parametric models e.g. COCOMO (BOEHM *et al.*, 2000). The most difficult costs at the beginning of a product lifecycle are the costs related to integration aspects.

## 3. Proposed model

The following section describes the proposed model and presents what should be done throughout product development process to make a cost estimate for mechatronic systems design. The purpose here is not to present a new model of mechatronic systems development;

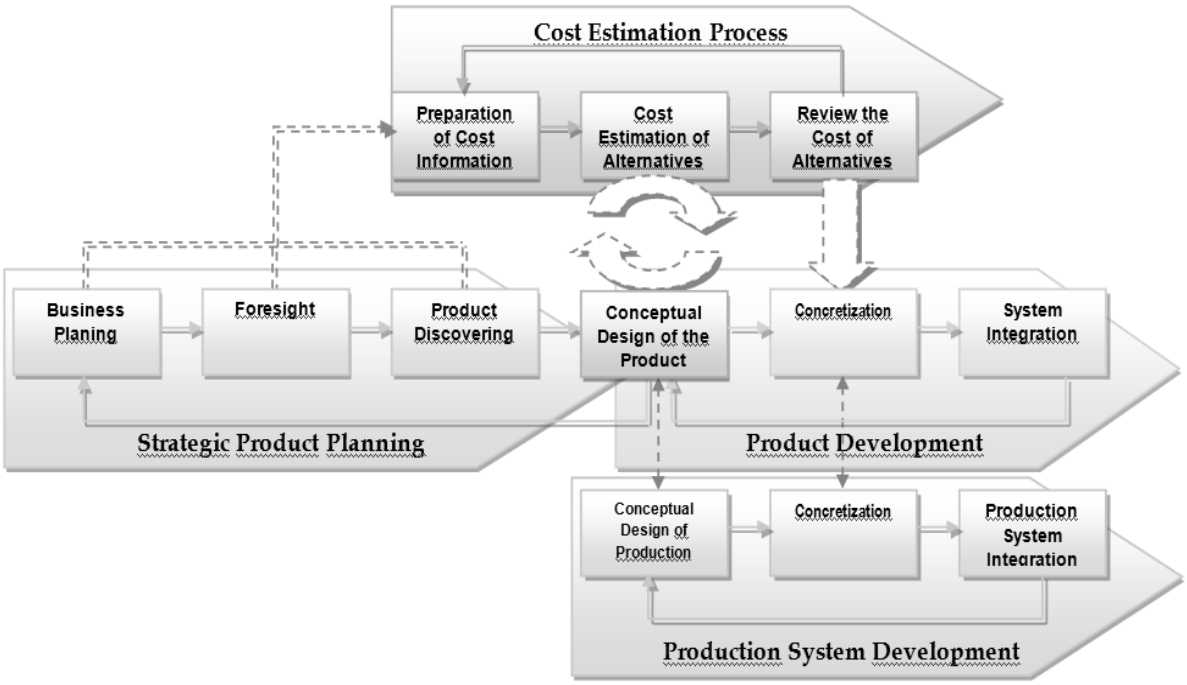
but to organize and insert information of the cost estimation process into an existing development model.

The model used for the insertion of cost estimation process in this paper is 3-cycle model, which consists of three main tasks: strategic product planning, product development and production system development (GAUSEMEIER *et al.*, 2011). A new cycle, the cost estimation process, will be inserted to the 3-cycle model.

The 3-cycle model integrates in its approach a V model. The 3-cycle model synchronizes the activities of product development with system development production in their conceptual phase; this is called integrative conceptual design. This integrative conceptual design approach is an advantage when compared to the other models.

The new cycle of cost estimation process can be divided into three main activities: preparation of cost information, cost estimation of mechatronic system alternatives and alternative costs reviewing to achieve the target cost. Figure 2 illustrates the main activities of cost estimation into the 3-cycle model.

Figure 2 - General overview of cost estimation model for mechatronic products




Source: Modified from Gausemeier *et al*., (2011)

The proposed model is synchronized so that cost estimation model activities and 3-cycle model tasks for mechatronic product development processes are executed in an integrative and simultaneous way.

### 3.1. Preparation of cost information

At the beginning of the product development process, cost information must be prepared and made available to be used in the analysis and estimation during mechatronics systems design.

The project team should research all necessary cost information about product functions. Product functions are important because their proper unfolding will be a basis for cost estimation. In this activity, information from different domains of mechatronic systems is identified. Mechatronic systems are multidisciplinary products, so the stakeholders involved in the preparation of cost information have a different domain (e.g. design, manufacturing, marketing, finance, purchasing). When preparing the cost information, it is important that the project team has an overview of different areas and factors affecting the product cost (ROZENFELD *et al.*, 2006).

The activity of preparation of cost information has four main tasks: collect information of similar mechatronic products, define a target cost, unfold the cost of mechatronic systems and collect information of domains of manufacturing and purchasing.

a) Collect information of similar mechatronic products: In this task the project team, along with the marketing department analyze the market information. Thus aiming to generate a consistent base of information about functions of similar products in development. This information aids cost estimation when the analog method is used and contribute to define a target cost.
b) Define a target cost: This task implicates a large number of variables related to market, the companies involved in the development process and company strategy. Taking into account the information related to market price of product and profit of the company, target cost of a mechatronic product is determined. Ferreira (2002) describes the procedure to define a target cost: first a market research is performed in order to understand the user needs, analyze trends between competitors and identify issues related to quality based on market feedback. Then, profit planning takes place, this time the finance department according to company's strategy determines the profit margin.

Finally, the selling price and target cost are defined by the project team in coordination with finance department and according to market, after studying actual prices of similar products from competitors as well as functions of these products. Two methods can be used to determine sales price and target cost, they are described in Table 1.

Table 1 - Methods for determining the sales price and target cost

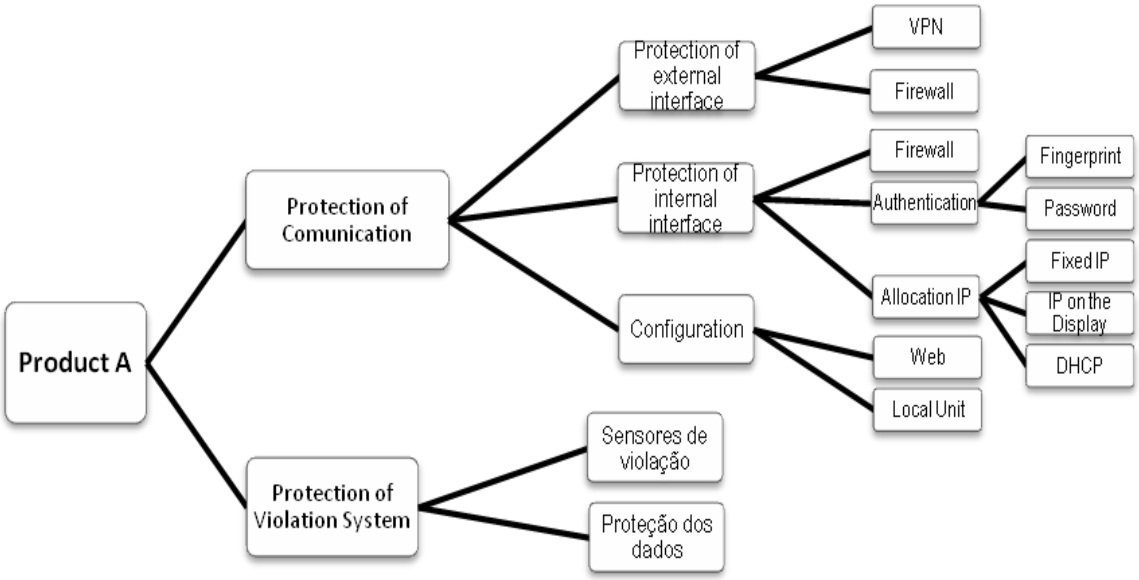
| **Sales Price of Mechatronic Product** | |
|---|---|
| ***Method Based on the Market*** | ***Method Based on Cost*** |
| The selling price is determinated by considering that the market price is the maximum that the customer pays for the product. | The selling price is determinated by adding a margin of profit established on the direct cost of the product. |
| Estimated selling price for new mechatronic products:_____ | |
| **Target cost of new mechatronic products** | |
| ***Method Based on the Market*** | ***Method Based on Cost*** |
| Target Cost = Price – Company Profit | Target Cost = Direct cost + Company Profit |
| Estimated target cost for new mechatronic products:_____ | |

Source: Modified from Ferreira (2002)

c) Unfold the cost of mechatronic systems: The project team seeks to establish the cost structure of the product. This structure will provide information to support the decision making process of mechatronic products design related to economic aspects. The information provided will compose the foundation for cost estimation of mechatronic products. This foundation will be established through the activities performed in the development process and the functions performed by the product. The cost structure will consequently offer an overview of the activities and functions that influence the direct cost of mechatronic products. Before beginning the cost estimation the activity mapping is performed. The level of detail of the activities depends on the products´ functions and the development model implemented by the company. Knowing the cost of the activities and tasks involved in the product design only, is not enough. Moreover, the unfolding from their functions is necessary. The determination of the functions is critical not only for cost estimation of the product, but also to trace and identify the costs and conceptions that are affected due to changes in its functional structure. This task is synchronized with the activities of conceptual design which establish a hierarchy of functions. The product should be broken down into functions

and sub-functions as show in Figure 3 until the unfolding does not cause more variation in the process.

Figure 3 - Unfolding of the functions of mechatronic products




d) Collect information of manufacturing and purchasing: The objective of this task is that the project team, simultaneously with the manufacturing and purchasing department collects cost information from the manufacturing process. Here, the components that fit with the production system and the components that need to be purchased are defined.

### 3.2. Cost estimation of mechatronic systems alternatives

The cost estimation is the activity by which the project team realizes a prediction, measuring in advance the efforts required to develop a product. This activity must be done in parallel with the phase of conceptual design so that the selection of the product solution is made attending at the same time, technical and economic aspects.

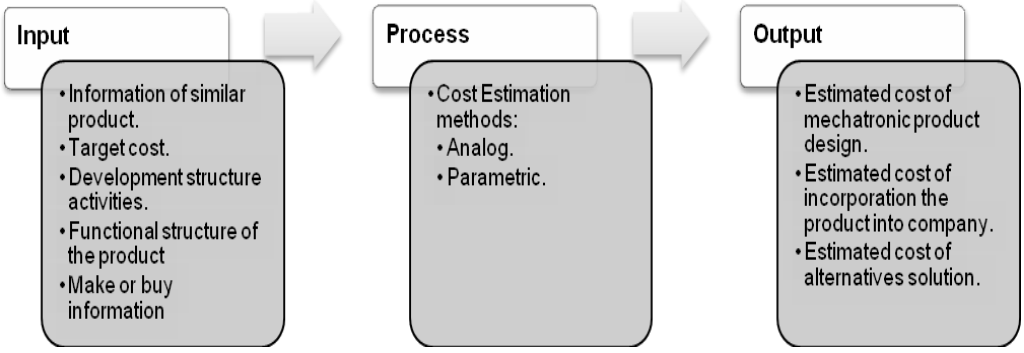
In the proposed model, the following is considered input information: cost information of similar products and product functions. This information is processed employing cost

estimation methods and tools. Figure 4 shows how cost estimation methods transform the input information into cost estimates.

This activity consists in three major tasks: development cost estimation, cost estimation of product incorporation in the company and cost estimation of product design alternatives.

a) Development cost estimation: The objective of this task is to calculate the development cost of mechatronic products based on effort and resources used in the activities of mechatronic products design. The development cost influences 5% of product total cost (BRUE; LAUNSBY, 2003). The input of this task is the unfolding of activities of product design. Each function is constituted by a set of interdependent activities. Activities and interactions between mechatronic systems having a large number of functions can be complex to identify. In order to have a more precise breakdown of the solution, the functions are categorized into modules: hardware (mechanical and electronic components) and software.

Figure 4 - Flow of information through the cost estimation process




b) Cost estimation of product incorporation in the company: The project team determines the cost of the product incorporation, this is, what is the impact the product will have on the structure of the company. The incorporation is a set of factors for admission or integration of the product in the company. The make or buy analysis is one of the techniques introduced in this task. It seeks to determine whether it is more advantageous to manufacture the products or to purchase them. This type of evaluation is based on comparisons of the performance level of the company versus the level offered by the market. The incorporation affects the accuracy of cost estimation, that is why it must be taken into account when carrying out this process.

c) Cost estimation of product design alternatives: In this task the project team uses the methods of cost estimation. Based on these, analog and parametric methods to estimate the cost estimation of mechatronic products are proposed.

- The analog method: aims to determine the direct cost of the mechatronic products based on historical information of similar products.
- The parametric method: determines the direct cost of the mechatronic products based on a mathematical relationship and some parameters related to products and processes. The parameters are based on the functional product structure, which originates standard costs that are related to estimation method.

It is necessary to gather the solution principles that compose it in order to perform the cost estimation of the alternatives of product design (PAHL; BEITZ, 2005). The cost of each solution principle must be estimated. Thus the economic evaluation of the product can be made taking into account the market and company strategy.

### 3.3. Review the cost of the alternatives

This activity supports the decision taking to get the closest alternative to target cost, it helps to decide which alternative should be reviewed or modified and makes a comparison between the estimated cost and target cost. If the estimated cost is greater than target cost, a modification can be performed seeking to achieve the target cost. In the case where estimated cost is less than the target cost functions can be added to the product or it can be modified. At the end of this activity the project team has enough information to choose the best alternative of conception.

## 4. Conclusions

The development of mechatronic systems, including mechatronic products is a challenge for academics and businesses. In this work the important of cost estimation in the early stages of mechatronic product design was emphasized.

The important of early stages of product design for success in new product design is widely referred in the literature highlighting the phase of conceptual design, in which a large number of strategic decisions about the product are taken, with strong influence on costs in subsequent product design phases. However, when researching about mechatronic products design in the literature it was noted that the cost estimation is not explored.

The proposed cost estimation model for early stages of mechatronic products design supports the base for decision making during the phase of conceptual design, giving form to the costs and scope of the whole project. Given a cost complexity, cost parameters and nonlinearities of a mechatronic product, the cost estimation process can be difficult, but still fundamental to guide designers through the development.

Therefore the main contribution of this work is that proposed model allows students and professionals without experience in costs, to have an orientation to estimate costs at the phase of conceptual design of mechatronic product. Also, it is the basis for the development of a computational tool and as well for the development and assessment of particular business models used in companies to support decision taking in the conceptual design phase. Through this contribution, strategic product decisions will be based on both technical and economical aspects related to the conception of mechatronic products. Furthermore, the model can be used in the training of students and as starting point for further researches.

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