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Cost modeling analysis in sand casting foundry

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Abstract

This paper proposes an enhanced Activity-Based-Costing (ABC) dedicated to the sand casting industry by combining a traditional ABC approach with a mix of dimensional analysis and linear regression method. The approach developed in the article is very general and can be used in other domains without problems. The method has been chosen based on an initial analysis of the existing cost modeling methods. This analysis shows clearly that the traditional methods focusing on the direct costs are not accurate for evaluating costs when overheads are representing more than 70% of this cost structure. This element combined with the fact that ABC approach is often based on a very limited number of synthetic cost drivers has lead us to develop an enhanced ABC model. This model stays coherent with the traditional ABC approach but it improves the ability of the model to fit more accurately with the reality of cost structures inside of companies.

Keywords: Cost, added value, direct cost, indirect cost, Activity-Based-Costing (ABC), cost drivers, dimensional analysis, linear regression.

1 Introduction

The official report *Improving Engineering Design, Design for Competitive Advantage* [1] published in 1991 by the United States National Research Council has completed analysis made by other scientists [2]. This report emphasizes on the fundamental impact of the design process in the innovation process and competition between companies. Design is the key factor of the product development process, both for technical and economical reasons [3]. The future of companies is strongly linked with their ability to combine high integrated values, high quality and low cost products meeting users' expectations. In order to ensure these objectives, the ability of a company to evaluate in a detailed manner the indirect cost structure is an element of fundamental importance. The objective of this paper is to analyze the cost structure combining a traditional ABC approach with a mix of dimensional analysis and linear regression method. This paper is an initial attempt to develop this type of cost analysis. At first, the present article makes a short literature review of some concepts related to cost and value. Second, a cost modeling model based on the techno-economical concept of cost and value is presented. Third, this article establishes basis for calculating the costs during the product development process based on combined approach.

2 Changes in the socio-economical context

The globalization process has increased the economical competition. It is crucial for companies to be reactive and flexible. This is obviously the case for foundry companies too. It means in practice for companies that the time needed to take a decision should be reduced and at the same time, the risks involving a wrong decision should be minimized. They should have adequate information at the right time in order to be able to evaluate the impact of the decisions on the entire life cycle of a product or process. Consequently, it is necessary to use appropriate metrics which provide reliable support for evaluating cost and time beforehand. These types of metrics should integrate conjointly technical and economical viewpoints. Such types of indicators have already been analyzed in several research projects [4] [5]. Traditionally, the costs models focus on the manufacturing of products. They provide evaluation of the cost of product. However, it is insufficient to use the manufacturing cost as a unique criteria for evaluating the profitability of a product. For example, the aeronautic industry has been using for a long time the cost of the life cycle (cost of a passenger for a plane in using condition [6]) to evaluate the profitability of their products instead of the manufacturing price. Indeed, the initial intuition of this article is that many foundry companies are faced with challenging situation regarding their future because the manufacturing cost is often used as unique driver for appreciating the profitability of a product. The same type of logic is also valid for the clients. Consequently, a cost model based only on the manufacturing cost creates a bias in the analysis of the profitability, evaluation and selection of industrial solutions.

In addition, it is important to compare the global cost of a product with the value given by the customer. Unfortunately, value and cost are not evaluated by using the same scientific method. Consequently, it is important to evaluate profitability of products from another perspective in order to be able to combine cost and value in a coherent manner.

During the last quarter of the twentieth century three major economical changes have occurred. The first is related to the economical environment which is characterized by an overproduction crisis. The second major change is related to the structure of the companies themselves. They should react quickly and it has implied drastic changes in the manner decisions at taken. The third change is related to the way the production has evolved. The production system, developed by Taylor in a period when the economical parameters were stable, is not valid anymore in most of the cases.

The consequence of these changes is that new costing approaches which go together with these changes have been developed [7]. The following section details the nature of costs structure involved in the design and manufacturing processes.

3- Analysis of the financial management models

The radical changes described above should also have affected the efficiency of the old financial models developed during the mass production development at the beginning of the twentieth century. Indeed, it has been underlined by many authors [9] [10] [11] that financial concepts commonly used by companies such as *selling price, cost price* and *financial margin* are based on outdated definitions. For example, the widely accepted relation presented in Eq.1 was true when the selling price was accepted as such and paid by the customers. Now the selling price is first depending on the price that the customer is willing to pay. This *selling price* depends on the value the customer gives to the product or service. Consequently, in the new system the *margin* is now the result and the relation takes the form of Eq.2. *Margin* and *selling price* became the objectives.

Selling price=cost price-margin **Eq. 1**

Margin =cost price- selling price **Eq. 2**

The same type of outdated scheme can be highlighted when calculating the profitability of a product.

Profitability = margin / selling price **Eq. 3**

The Eq.3 can be highly questioned because the advantage for a company to sell a product is depending on the *economical benefit* for the company. The *margin* calculated by using the *cost price* is inferior to the real *economical benefit* for the company because the potential benefit is much higher and encompasses several other elements such as the image and notoriety of the company. In addition, in Eq.3, the *selling price* should be similar to *the effort of the company* to produce a certain product, but the selling price is in reality the effort of the customer, not *the effort of the company*.

This short analysis demonstrates that new a scheme is required. According to Perrin [11] indicators based on cost can be classified in two main categories, the cost of the product and the budget. The cost of the product is used in methods such as the target costing or the activity based costing. The idea is to define a *target cost* as an objective. The *price cost* should then correspond to this *target cost*. The indicator used to analyze this approach is the ratio between the *effective price cost* and the *maximum objective price cost*.

Regarding the budget and especially the initial funded budget for the development of the product, the indicator used is the ratio between the *exceeded amount* and the *initial funded budget*.

4 Direct costs and indirect costs

The evolutions described above have strongly affected the nature of the cost inside a company. In the previous scheme characterized by the stability of the external environment, the costs were divided in the following manner by the analytical accounting method: around 70% for the direct cost (e.g. fixed costs associated with the production of the casting) and 30% for the indirect cost (e.g. all the cost such as overhead, administrative costs, design costs, tooling and process ‘prove-out and “debugging”) [18]. This approach was valid since the direct cost was representing around three quarters of all costs. At the moment the structure of the cost has been inverted because companies are faced with constraints such as flexibility and adaptability. Consequently, the indirect costs related to the market analysis, development and design have exploded. This can be visualized according to the Figure 1 from Perry et al. [12].

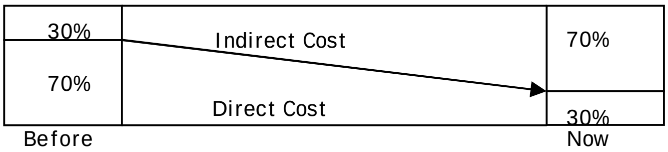

Figure 1: Evolution of the repartition of the direct and indirect cost

A more detailed analysis shows that in addition to this shift between the direct and indirect cost related to these two periods; decisions take during the study phase are affecting a lot the future expenses made during the industrialization and production phases. Consequently, it is obvious that economical savings can be made much more easily if concentrating on the design aspects. This can be seen according to the Figure 2 from Alcouffe et al. [8].

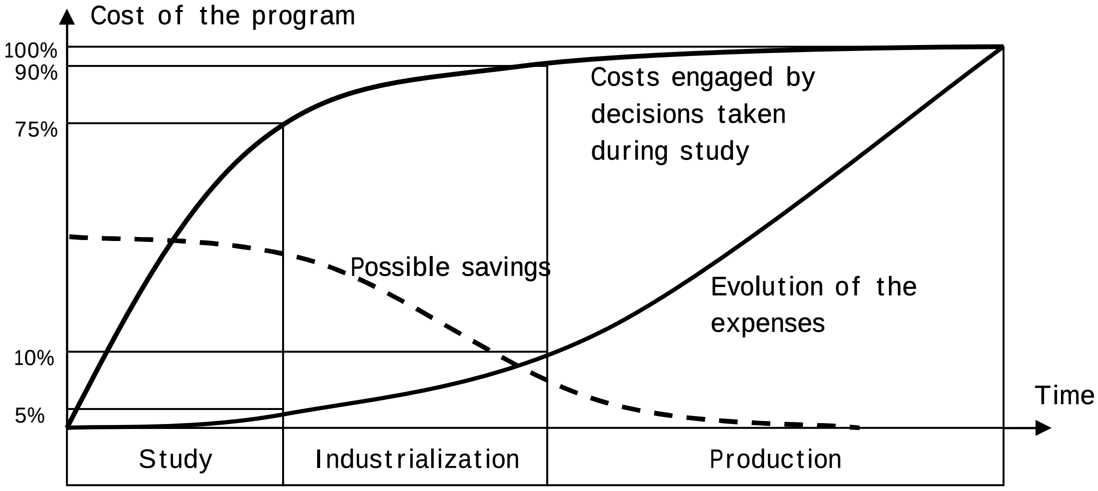

Figure 2: Evolution of the costs during the life cycle of a product [8]

Based on this analysis, the structure and the models of the cost calculation should be deeply modified by integrating at the very early stage appropriate methods (e.g. design evaluation methods, cost evaluation methods, etc…) in order to optimize products from different viewpoints. In our case, we will concentrate on the cost modeling of a product in order to take into account the indirect and direct costs. Design choices are cheap in term of resources but can become later very expensive in production when it is extremely difficult to make changes.

5- Activity based costing

The previous section has shown that it is of fundamental interest to control cost from the very early stage of the development process. This idea is not new and for more than ten years, several approaches have been developed in order to take into account these aspects. Two major actual methods can be listed in this article, the *target costing* and the *Activity Based Costing (ABC)*. Specialized literature in financial management has predicted some years ago than ABC approach will represent a fundamental change in the approach of the cost control and analysis. Nevertheless, a very small amount of companies are currently using this approach, less than 5% according to Mévellec [14]. Most of the companies are using the direct cost model (English speaking countries and North Europe), or the complete costs model (France and some other European countries).

The goal of this section is to present the fundamental concepts involved in the ABC approach. In a traditional cost structure approach, it is considered that a product is consuming directly resources. This scheme is valid for the direct resources which are affected without ambiguity to the product. Nevertheless, the attribution of the indirect costs to the cost of the product is not reliable and subject to several critics in the cost accounting literature [7, 9, 13, 14, 15 and 20]. Consequently, a new approach called the ABC approach has been developed, in order to grasp in a more realist manner the reality of the cost structure. In this method, the production of a product requires several *activities* and those activities are themselves consuming *resources*. According to Milkoff [7], several activities can be clustered in groups called *processes*. We argue that this type of classification suits to our purpose too because manufacturing activities are clustered according to the technical characteristics of different processes. The Figure 3 presented below summarizes the fundamental concepts of the ABC approach.

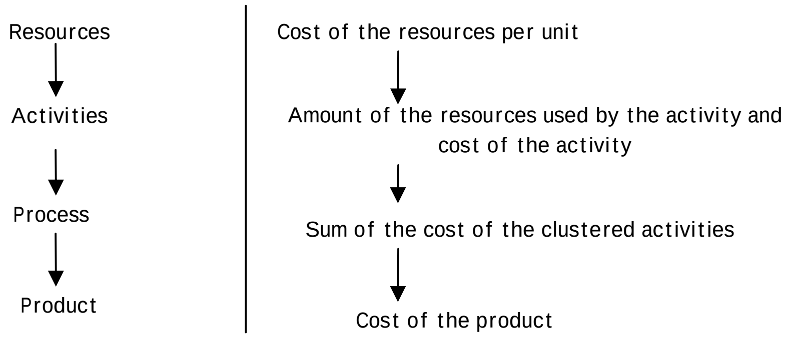

Figure 3: ABC framework

There exist relations between the activities and processes necessary to create a product. The creation of the model requires searching the causes which influence the activities and the unit used to measure these causes. The causes of the activities are called *cost drivers*. The structure of the cost drivers will be analyzed later in this article. Nevertheless, the entire framework can be summarized according to the Figure 4 . The cost drivers' structure will be described later through the use of a small example. A cost entity can be described using the SADT formalism of the Figure 5.

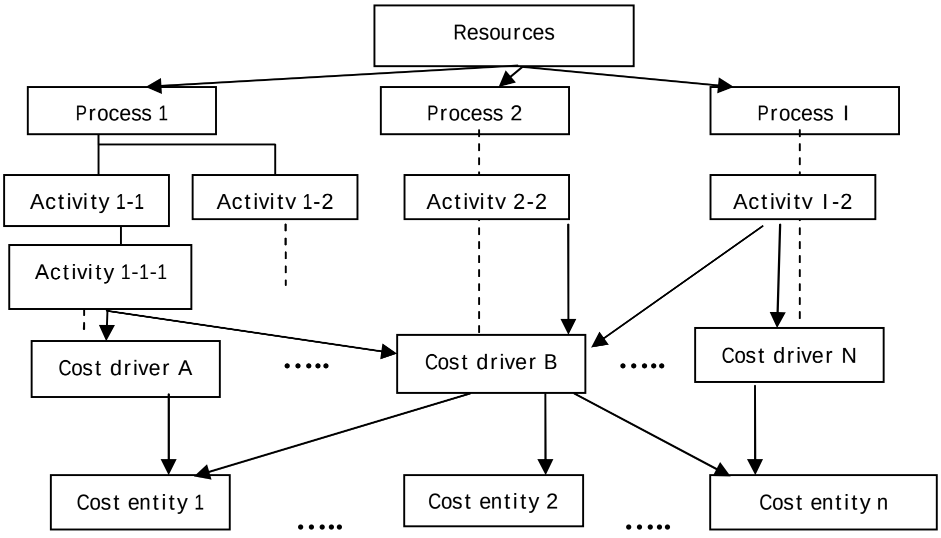

Figure 4: The generic Activity-Based-Costing model [16]

6- Cost entity and cost drivers

General model

The previous section has described in a summarized manner the ABC model. This section is analyzing the generic structure of a cost entity from an SADT viewpoint [21]. Modeling methods such as UML or IDEF can also be used. In future work the IDEF3 [22] approach and probably the UML approach will be selected to create a portable ABC model dedicated to foundry industry.

A cost entity in the SADT viewpoint can be presented as a "box" which transforms the elements which cause the cost into an output, the cost. The inputs are measured using the 7 based quantities of the SI system and an additional quantity of information [19]. The output is measured by using a cost quantity [19]. The Figure 5 summarizes this cost entity model and its generic law.

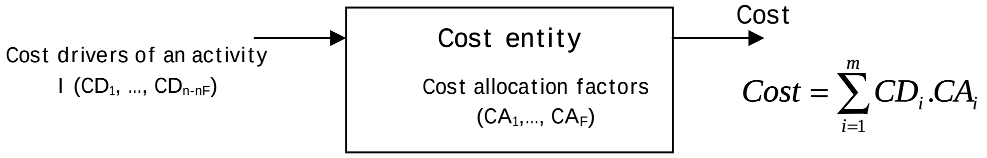

Figure 5: Cost entity structure

At this stage of the presentation, it is useful to present a short example in order to highlight a potential drawback of the cost driver method. The case study selected has been adapted from Andrade et al. [23] and it represents an example from a sand foundry workshop. The example involves the molding of two steel parts denominated product A and product B. The molding process under consideration involves five types of resources: raw material (steel), machines for delivering the sand, direct labor for manufacturing and cleaning the products, indirect labor for quality control and supervision and the sand mold, and vehicles to deliver the products.

Resources such as design, workspace, maintenance and administration are not included in this basic example. The raw material is also considered to be obtained from a sole supplier. The ABC model resulting from this simplified example is presented in the Figure 6.

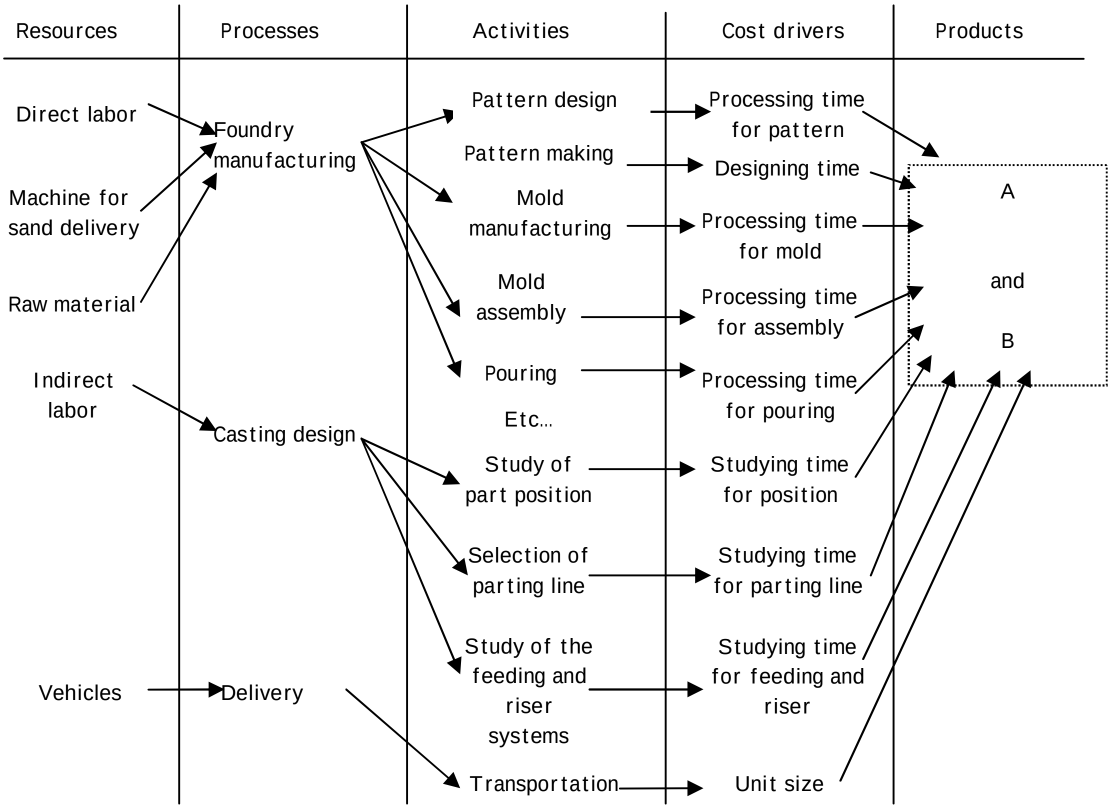

Figure 6: Simplified ABC model of a foundry company

It is important to notice that most of the ABC approach practitioners are only using a simple set of cost drivers to describe complex activities.

This is the case in the example of the Figure 6. Consequently, it results in a linear cost function for each activity. This linear behavior of overhead costs is often not fulfilled in real-world applications. An article from Noreen and Soderström [24] has already provided empirical evidence against proportionality in the medical sector. It is a reasonable hypothesis to consider that the proportionality is not valid in the foundry industry either. The reason against the proportionality hypothesis is obvious as explained by Homburg [25]:"When overhead resources are not perfectly flexible, under or over capacities as well as costs for adjusting capacities will results". Consequently, the law presented in the Figure 5 is over simplified and can not provide a sufficiently accurate model for cost evaluation.

This paper proposes a method to overcome this weakness. The idea consists of keeping an aggregated unique cost driver to conserve the simplicity of the approach but this cost driver will become a function of several sub cost-drivers.

Example: Design of a pattern

In order to present the approach lets us focusing on the activity of designing the pattern presented in Figure 6. Designing a pattern requires taking three fundamental decisions according to Stoll [18]. These three major decisions include selection of the fabrication method, the tooling material and the tooling approach to be used.

The present article focuses on modeling the cost of the sub-activity called *selecting the fabrication method of the pattern*. A list of the major factors affecting the selection of the fabrication method can be established. The most important factors include:

- Lead-time requirements,
- Quality requirements (dimension tolerance, surface tolerance, geometric tolerances),
- Cost requirements,
- Complexity of the pattern geometry
- Capability of the manufacturing process,
- Material of the pattern (hardness, melting temperature).

These factors can be measured by using quantities belonging to the enhanced system of quantity (composed of 9 basic quantities) proposed by Coatanéa [19]. The initial International system of quantities composed of 7 quantities has been enriched by the economical quantity in order to analyze economical elements and by the quantity of information used in order to analyze transfer of information. The interest of the information quantity is described below.

Complexity is a human judgment and complexity is associated with the amount of information a human as to deal with in order to take decisions. Consequently, it is logic to argue that the concept of complexity can be associated with the amount of information. The amount of information can be computed by using the theory of information developed by Shannon [26]. This computation has been made by Coatanéa [19] in order to define an aggregate measure of the complexity. It is referred in the following paragraphs to the Shannon (Sh), which is the selected unit for measure of information [19]. It is of course possible to compute sub-complexity metrics if more detailed analysis is required.

The capability of a manufacturing process can also be analyzed by using the same quantity because the capability can be viewed as the degree of complexity that a manufacturing system is able to deal with. It is possible to attach quantities to all the factors introduced above. These factors are the cost drivers of the sub-activity fabrication methods. The following table presents these cost drivers and their quantities.

Table 1: Cost drivers of the selection of the fabrication method of the pattern

Cost drivers of the activity *selection of the fabrication method of the pattern*	Quantities
Lead-time (LT)	T
Dimension tolerance (most accurate) (DT)	L
Surface tolerance (most accurate) (ST)	L
Geometric tolerance (most accurate) (GT)	L
Cost requirements (CR)	C
Complexity of the pattern (CP)	Sh
Capability of the manufacturing process (CaP)	Sh
Melting temperature of the material (MT)	K
Hardness of the material (H)	L

The cost drivers are now listed for this sub-activity. The model presented in Figure 5 takes then the following form:

$$Cost = PT.CA \qquad \textbf{Eq. 4}$$

Where:

PT has the dimension of Time (T),
CA has the dimension of cost/time (CT^{-1})
With:

$$PT = f(LT, DT, ST, GT, CR, CP, CaP, MT, M) \qquad \textbf{Eq. 5}$$

Dimensional analysis states that the characteristic value *PT* can be decomposed in one power law expression with a function *f* of *m* dimensionless groups $\Pi_1,\ldots,\Pi_2$, which also have a power law expression as a function of the parameters. The Eq.6 also respects the quantity constraint which requires then the dimension of *PT* to be similar to the dimension of the right part of the equation. The following expression can be written:

$$PT = a_0 \prod_{i=1}^{n} X_i \, f(\Pi_1,\ldots,\Pi_m) \qquad \textbf{Eq.6}$$

Where:
X_j are the cost drivers not integrated in the dimensionless numbers
a_0 is a constant of the model,

For simplicity, we will assume that the function *f* can be approximated by a power law. This is reasonable, given that most of the behavior of the dependent variables (e.g. the sub cost drivers) is captured by the power law expression and *f* shows small, smooth and monotonic variations within a regime (a regime means that the same physical factors are dominant for all the observations used to built the input data set of our model). Consequently, the Eq.6 takes the following form:

$$PT = a_0 \prod_{i=1}^{n} X_i \; \prod\Big(\prod_{k=1}^{l} X_k^{b_k}\Big) \qquad \textbf{Eq. 6}$$

Where:
$a_0 \prod_{i=1}^{n} X_i$ is the part containing some of the cost drivers not integrated in the dimensionless groups,

$\prod_{k=1}^{l} X_k^{b_k}$ are the dimensionless groups,

In our example, the dimensionless groups can be computed using the algorithm developed by Coatanéa [19]. According to this algorithm it is possible to create 4 dimensionless groups. Then the model can be written:

$$PT = a_0.(C.MT.LT).\Pi_1.\Pi_2.\Pi_3.\Pi_4 \qquad \textbf{Eq. 7}$$

With:

$\Pi_1 = CaP.CP^{-1}, \Pi_2 = GT.DT^{-1}, \Pi_3 = ST.DT^{-1}, \Pi_4 = H.DT^{-1}$,
a_0 having the dimension 1/Cost.Temperature ($C^{-1}K^{-1}$),

The final cost model for the sub-activity is then:

$$Cost = CA.a_0.(C.MT.LT).\Pi_1.\Pi_2.\Pi_3.\Pi_4 \qquad \textbf{Eq. 8}$$

We have obtained a cost model for the sub-activity called *selecting the most appropriate fabrication method for the pattern*. The quantitative model for this sub-activity can be obtained easily by analyzing quantitative data coming from pattern makers and foundry industry. This model is certainly much more accurate than the linear model proposed at first in Eq.4. This has to be proved by practical use inside of companies. In addition this model has to be extended in order to create an entire ABC cost model.

7 Conclusion

This short study has introduced a cost model based on the ABC approach. We have proposed to enhance this model by using a combination of dimensional analysis approach and linear regression approach. Finding the quantitative parameters of the Eq.9 will require a second step which is the collection of experimental data from foundry companies. Our future research will focus on some other issues related with cost modeling; the analysis of the existing interactions between the activities, the creation of a portable computer model able to be integrated in companies and the implementation of an XML platform aimed at transferring quantitative information into the portable model and from the portable model in direction of other company tools. The approach described in this paper is very general and can be applied to other domains without problems.

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