Activity-based cost management for design and development stage

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Abstract

The fierce global competition in the international markets forces manufacturers to compete in quality, cost, and the time to market aspects of their products. Knowing the cost of the manufactured components is essential for efficient operation and competitive production.

The current evolution of competitive manufacturing requires a shorter market life span of products—emphasizing the design and development phase of the product life cycle. Thus, it has become more important to analyze the cost of the design and development phase accurately.

Activity-based costing (ABC) has become a mature cost estimation and accounting methodology. Using ABC for cost estimation of manufactured parts is being practiced today with acceptable rate of success. Cost estimation of the design activity on the other hand, has been nebulous and hard to implement.

This paper presents a methodology of using ABC to evaluate the cost of the design and development activity for machined parts. The methodology is demonstrated on a sample part being produced in a controlled manufacturing facility.

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1. Introduction

Modern-day manufacturing operations are facing a fierce global competition and the need to increase productivity at reduced cost. Estimating the various manufacturing costs more accurately has become a strategic objective.

The functions of cost estimating include: (Malstron, 1984, p. 9)

- check quotations from suppliers,
- aid the make-or-buy decision,
- evaluate product design alternatives; cost estimations are particularly useful at the early design of a product where 70% of its cost is determined (Duverlie and Castelain, 1999),
- assist long-term financial planning,
- help control manufacturing cost,
- provide standards for production efficiency.

Traditional cost systems are known to distort the cost information by using traditional overhead
allocation methods (that rely on direct resources such as labor hours). Activity-based costing (ABC), on the other hand, has gained the recognition of a more accurate cost estimation and calculation method. The ABC method traces the cost via activities performed on the cost objectives (production or service activities), giving more accurate and traceable cost information. Using ABC can lead to classifying activities as value-added and non-value-added; and allow for elimination of the non-value-added activities (Gunasekaran and Sarhadi, 1998).

The demands of the market keep reducing the life expectancy of products, causing the design and development phase to become more pronounced in the overall product life cycle. Thus, in order to correctly account for the product costs, the design and development cost have to be accurately measured. The design and development phases include all the activities starting with the requirements of the customer, through the design of the part, its process planning and finally the making of a prototype.

This paper demonstrates the application of ABC towards analysis of the design and development costs. The methodology follows these steps:

1. Identify the resource centers used for the design and development.
2. Identify the overall cost associated with these resource centers.
3. Find the cost drivers for the resource centers.
4. Identify the activities that participate in the design and development process. These activities are analyzed using the IDEF0 methodology (Ang et al., 1994).
5. Calculate the cost of the activities based on resource consumption.
6. Find the activity cost drivers and calculate their values.
7. Calculate the overall process costs based on the activities performed.

This paper is structured as follows: Section 4 provides an example of cost analysis of the activities involved with the product development process of rotational parts. Section 5 provides a more detailed analysis of some activities with their associated costs, and Section 6 provides a summary and future research.

2. Literature review and background

Cost estimation methods can be classified as: intuitive, analogical, parametric, and analytical methods. The intuitive methods are based on past experience of the estimator. The analogical methods estimate the cost of products using similarity to other products with known cost. The parametric methods estimate the costs of a product from parameters, which are usually used by the designers. These parameters influence the cost in a known way represented usually by a simple equation. Analytical methods such as ABC allow evaluation of the cost of a product from a decomposition of the work required into elementary tasks, operations or activities with known (or easily calculated) cost.


Different cost models have been developed for various manufacturing applications. Examples include injection molding process, PCB manufacturing and assembly (Ong, 1995), and gear drive manufacturing (Yang and Lin, 1997). Geiger and Dilts (1996) presented an automated design-to-cost model by integrating costing into the design decision. Asiedu et al. (2000) considered the uncertainties associated with the cost model.
parameters such as time, inflation, labor rates, and failure rates by employing non-parametric estimation techniques.

Some cost analysis of manufacturing operations use features technology. This approach is useful especially when the designer uses features as the design building blocks. Feng et al. (1996) presented a feature-based cost evaluation model in which the geometry of features and relationships between features are used for cost estimation. Yang and Lin (1997) proposed a framework for feature-based early cost estimation according to the shapes and precision of features. Zhang and Fuh (1997) used a back-propagation neural network for a feature-based cost estimation. Veeramani and Joshi (1997) used characteristics of several features (such as dimensions and surface finish requirement) to directly determine the total resource requirement for manufacturing the feature. Roberts and Hermosillo (2000) estimated time and cost for small surface units, called primitives, using approximated tool paths and process parameters for available factory resources.

Parametric cost estimation methods seek to evaluate the costs of a product from parameters characterizing the product without describing it completely. This method meets the criteria of precision and speed of results with well-defined part families but without good explanation facilities. At least three types of parametric methods have been identified (Duverlie and Castelain, 1999): The method of scales, statistical models, and cost estimation formulae. Boothroyd and Reynolds (1989) demonstrated the use of volume or weight of typical turned parts as parameters for approximating cost estimates.

A relatively new cost estimation approach is the ABC method. ABC systems help designers to understand the design parameters that create demands on indirect and support resources. A review and comparison of traditional cost accounting and ABC analysis can be found in Park and Kim (1995).

ABC is often used as a part of total cost management. ABC system differs from traditional system in two ways: first, cost pools are defined as activities rather than production cost centers and secondly, the cost drivers used to assign activity costs are structurally different from those used in traditional cost systems (Lewis, 1995).

The popularity of ABC has grown at a fast pace in the 1980s due to the promotion of organizations such as computer-aided manufacturing-international (CAM-I) and the National Institute of Management Accountants.

ABC has been applied to various industries (Tsai, 1996) such as electronics (Merz and Hardy, 1993), automotive (Miller, 1994), aerospace and defense (Soloway, 1993), airplane manufacturing (Haedicke and Feil, 1991), shipbuilding (Porter and Kehoe, 1994), and telecommunication (Hodby et al., 1994), among many other areas of application.

The ABC method models the usage of the organization resources by the activities performed and then links the cost of these activities to outputs, such as products, customers, and services.

In traditional cost systems, direct materials and labor are the only costs traced directly to the product. Manufacturing overhead costs are not traced, but allocated to the production departments. They may be traced to an activity or a service department or some other cost objective, but not to the product itself. The ABC method identifies the activities that drive costs by consuming resources. Cost drivers are items such as number of units produced, labor hours, hours of equipment time, or number of orders received.

ABC assigns activities’ cost to units of production, or other cost objects such as customers, services, etc. Activities can be categorized into four classes: unit-level activities, batch-level activities, product-sustaining activities that are associated with a given product as a whole, and facility-sustaining activities, which cannot be directly linked to any one product. Examples of the later are building maintenance, or general management activities.

The advantages of ABC include the following: improve the accuracy and relevance of products costing, provide timely cost information suitable for decision-making and allowing more detailed tracking of indirect cost-to-cost objectives.

The shortcomings of the of ABC methods include the following: doing little to change old
management behavior, not driving companies to change their fundamental views about how to organize work and to satisfy customers efficiently. Finally, the ABC method requires additional effort and expense in obtaining the information required for the analysis (Lewis, 1995).

Examples for applications of ABC are presented by Lee and Sullivan (1998) who developed an ABC model to estimate product cost at the conceptual level of PCBs design. In their work, cost drivers are related to the design parameters established during the conceptual design stage. Tseng and Jiang (2000) developed an ABC analysis model for evaluating the different manufacturing costs for multiple feature-based machining methods. The activities in the model include tool setups, fixturing setups, and machining tool paths. The shape of the parts is restricted to prismatic parts and prismatic features suitable for machining on 3-axis milling center.

3. Implementation of the ABC method

In this research, the ABC method for cost estimating is implemented using the steps presented in Fig. 1 (modified from Cooper and Kaplan, 1999, p. 210).

The implementation of the ABC approach follows these steps:

3.1. Identify cost centers

Cost centers are the resources that are used directly to produce the end product. Cost centers include human resources such as design engineers, project managers, manufacturing coordinators, and manufacturing engineers. Additionally, cost centers include major equipment such as the vertical milling machining center, CMM center, laser cutting center, material handling center, tooling center, and others.

3.2. Analyze indirect costs and calculate their cost-drivers rates

Indirect expenses are the overhead costs that need to be allocated to the end products. These expenses include room rent, cleaning, computer purchasing and maintenance, heating gas, water, software, network administration, paper, printers, copy machine toner and lease, and the like.

Indirect resource cost drivers are determined in this step. For example, the resource cost driver for heating gas is the square footage of the cost center, while the network, computer, and computer maintenance costs are allocated by number of user hours. Each resource cost-driver rate is calculated by dividing the total annual cost of the resource by the total number of cost drivers used in 1 year.

The indirect resource rate is calculated by

\[
RR(\text{resource rate}) = \frac{\text{Total cost for 1 year}}{\text{Resource drivers spent in 1 year (RD)}},
\]

\[1\]

3.3. Assign resources to each cost center and determine cost center driver rates

In this step, the cost of indirect resources is allocated to cost centers, such as the design engineer, CNC turning center or material handling center, based on the resource cost drivers.

In this step the total cost for each cost center is calculated. Then for each cost center one cost driver is identified. For example, the driver for a machining center is the machining time, while the driver for the material handling center is the number of trips. Lastly, in this step, one driver rate is obtained for each cost center.

The total cost for each cost center in 1 year can be given by

\[
\text{Total annual cost for cost center} = \sum_{i=1}^{\text{number of resources}} \frac{RR \times RD}{\text{Cost center drivers spent in 1 year (CCD)}},
\]

\[2\]

and RD is the amount if each resource driver spent by the cost center in 1 year.

\[
\text{CCR}(\text{Cost centre rate}) = \frac{\text{Annual cost of center}}{\text{Cost center drivers spent in 1 year (CCD)}},
\]

\[3\]
3.4. Identify activities

Identify the activities that take place in the product development process. These activities are modeled using IDEF0. Major activities, such as design, and CNC prototype machining are decomposed into more detailed activities, which are presented in the next section.

3.5. Analyze each activity and find the total cost for each activity

Based on cost-center resources devoted to each activity, the total cost for each activity is determined. This cost is calculated by using the cost-center drivers’ rates multiplied by the amount of the drivers consumed by each activity.

3.6. Define activity drivers for each activity and find activity cost-driver rate

An activity cost-driver is any factor that directly explains the cost incurred by the activity. Usually, ABC systems use different types of cost drivers such as transaction drivers, which represent the number of times an activity is performed, or duration drivers, which represent the time it takes to perform an activity. Some cost drivers are easy to trace, such as machine hours, which can be used to explain the cost of the machining activity, while other drivers need a more innovative definition.

The activity cost-driver rate (ACDR) is obtained by dividing the total cost for each activity by the magnitude of the activity cost driver.
The ACDR for one activity is calculated using the following equation:

\[
\text{ACDR} = \frac{\text{Cost of one activity}}{\text{Activity cost driver spent}} = \sum_{i=1}^{\text{number of cost centers used}} \left( \frac{\text{CCR}_i \times \text{CCD}_i}{\text{ACD}} \right),
\]

(4)

where CCD\(_i\) is the amount of the driver of center \(i\) used for the activity, and ACD is the amount of the activity’s cost driver used. ACDR is the activity cost-driver rate cost.

3.7. Estimate the cost of new parts via activity cost-drivers spent

Finally, the cost of each product is defined by the activities used, and the magnitude of their cost drivers.

Total cost of one part

\[
= \sum_{i=1}^{\text{number of activities}} (\text{ACD}_i \times \text{ACDR}_i).
\]

(5)

3.8. Difference and similarity between this implementation and traditional ABC implementation

In this implementation there is an added stage for allocating the indirect costs to the products, namely the cost centers and their cost drivers. In this method, the indirect expenses such as gas and building cost are divided to the cost centers, and each center is assigned a cost driver. These cost centers are then associated with the activities, and activities cost drivers are computed. These activity cost-drivers are then used to find the cost of the complete product.

The translation of the indirect costs to cost centers follows the traditional cost accounting. This makes cost estimating simpler and easily understood by users, especially users with traditional cost accounting background.

In a traditional ABC system, all the indirect expenses including utilities, computers, and CNC machines and tools may participate directly in activities, making the analysis more complex or less accurate.

4. Example: design and development of rotational parts

This example demonstrates the cost analysis of rotational parts in a medium size design and development specialty shop. More specifically, the analysis describes the cost of designing and developing the part described in Fig. 2.

4.1. Cost of indirect resources and their drivers

The expenses of the shop are the costs of indirect labor, materials and supplies, utilities, equipment, buildings, and capital, which appear in the general ledger accounts and are traced to the traditional departments and responsibility centers. Table 1 lists all indirect resources and resource drivers employed in the shop. The resource cost-drivers rate is calculated from Eq. (1).

4.2. Design and development cost centers (direct resources)

The activities performed during the design and development phase can be divided into the following cost centers:

- Engineering:
  - Design center,
  - Project manager,
  - Manufacturing engineer,
  - Technician,
- Vertical milling center,
- 3-Axis mill-turn center,
- Laser cutting machine,
- Water-jet cutting machine,
- Sandblasting machine,
- Welding center,
- Tooling center,
- CMM machine,
- Rapid prototyping machine,
- Material handling center.

The indirect expenses assigned to the machines include annualized depreciation calculated as \(P(i(1+i)^n)/(1+i)^n - 1)\) where \(P\) is the current sum paid for the equipment, \(i\) is the interest rate,
and $n$ is the economical life of the equipment (assume $i = 6\%$, and $n = 7$).

### 4.2.1. Rates for cost centers

Total cost of cost centers for 1 year is the sum of all expenses (resources) spent by each cost center. These expenses are collected from the traditional costing system. The costs related to the building are allocated by square feet used by each cost center per year, while computer cost related to employees are allocated by number of employee hours.

Cost drivers for the human resources such as project manager, manufacturing coordinator, and technician are labor hours. The cost drivers for the machining centers are the machining hours, while the cost driver for the material handling costs is the number of trips of the forklift. Similarly, the cost driver for the tooling center is the number of tools used. The list of cost centers, their cost driver and the drivers' rate is presented in Table 2. The cost-center rate is calculated from Eqs. (2) and (3).

### 4.3. Activities analysis

The activities involved in the design and development of a product are modeled using IDEF$0$ diagrams. Table 3 lists the activities required to finish one rotational part, and Figs. 4–8, in Appendix A, present the corresponding IDEF$0$ diagrams.

As shown in Table 3, the process of product development requires the project manager and the designer to talk to the manufacturing engineer about the part requirements. The cost centers employed in this activity include the designer, project manager and manufacturing coordinator. The discussing time is determined mainly by the complexity of the part to be machined. It has been
found that a good estimator of the discussion time is the number of tool changes that take place during the machining stage.

After the manufacturing coordinator receives the drawing from the designer, the process plans are generated as well as the NC codes (via CAM software). The time for this activity is similarly determined by the complexity of the part as expressed by the number of tool changes.

After confirmation of the process plan by an inner customer (designer or project manager) or an external customer, the part is ready for development. The following activities are Purchase Material (activity A3121) and Deliver Material (activity A3122). The material handling center become involved with the material handling activity, using the length of each rotational part as the activity cost driver. The part’s length is a local parameter that correlates with the number of material handling activities (longer parts require more trips).

Before testing the NC program for the part, the manufacturing technician is required to set up the fixtures (activity A31341) and perform the cutter setup (A31342).

The activity Run Test part (A31343) uses more resources than other activities, and experience shows that this activity needs more time than the other activities. In this activity there is a need to change the cutting parameters, recode the NC programs, and perform similar adjustments before full production can start. Thus the activity cost-driver “Machining time” can be further refined.

4.4. Results

4.4.1. Input parameters

Based on the above analysis the following input parameters are used for estimating the cost of the rotational parts: part length, number of orders, number of cutters, number of setups and machining time (hours). All the activities that participate are driven by those inputs.

The calculated costs of the various activity drivers, the drivers consumed by the example part, and the cost of those activities is presented in Table 4.

From ACDRs in Table 4, the total costs for design and development of the sample rotational
part is given by

\[
\text{Total cost} = 6.59 \times \text{Number of cutters} + 934.54 \\
\times \text{Machining hour} + 0.22 \times \text{Part length} \\
+ 0.38 \times \text{Number of orders} + 1.57 \\
\times \text{Number of setups} + 1.45 \\
= $241.76. \tag{6}
\]

This analysis leads to the conclusion that the main resource spent by the part is the cost of manufacturing coordinator, which occupied about half of the total machining cost. In terms of activities, **Run Test Part**, **Machine Prototype** and **Discuss Product** used most of the resources and thus the cost.

This data is presented in [Fig. 3](#).

**Fig. 3(a)** is derived directly from **Table 4**. The cost of the cost centers as presented in **Fig. 3(b)** is derived from a more detailed description of each cost center and the activities that it supports. This straightforward analysis is omitted for sake of brevity.

### 4.5. Comparison between ABC and traditional cost

In order to compare the cost calculated using the ABC approach to the cost calculated using traditional methods, three sample parts were used. The cost comparison of the parts is presented in **Table 5**. The table shows a moderate difference between the ABC and the traditional cost estimates.

In the traditional cost estimation method we only consider the machining time, as an instrument to load overhead, without considering the activities performed in more detail.
The traditional system tends to underestimate the time it takes to make a prototype part, and to adjust the manufacturing parameters (which is the major part of the cost). The discrepancy between the ABC and traditional cost estimates grows as the parts become more complex, which require more extensive development and experimentation with the manufacturing procedures.

5. Decomposition of activities

5.1. Decomposite the activity: run test part

In order to enhance the precision of the cost analysis, the more crucial activities can be broken into more detailed elements, allowing a more accurate tracking of the cost. As mentioned above, the Run Test activity consumes the lion-share of the cost for machining. Thus, in order to allow for a better analysis of the cost elements, the activity is divided into more detailed elements shown in Table 6.

Based on Table 6, a more precise way to calculate the activity’s cost is

\[
\text{Cost for Run Test of one part} = 0.07 \times \text{Number of cutters} + 766.77 \times \text{Machining hour} + 0.18 \times \text{Number of dimensions} + 0.11. \tag{7}
\]

Then the total cost in Eq. (6) can be expressed now in more detail by

\[
\text{Total cost} = 6.66 \times \text{Number of cutters} + 926.25 \times \text{Machining hour} + 0.22 \times \text{Part length} + 0.38 \times \text{Number of order} + 1.57 \times \text{Number of setups} + 0.18 \times \text{Number of dimension} + 1.66 = $241.76. \tag{8}
\]

![Fig. 3. (a) Cost of various activities. (b) Cost of cost centers.](image)
This cost is calculated by replacing the cost of Run Test Part activity in Table 4 with Eq. (7).

5.2. Decomposite the activity: Machine Prototype

Similarly, a more detailed analysis of the activity Machine Prototype is provided in Table 7.

Based on Table 7, we have the following equation to calculate the cost for running test part

\[
\text{Cost for Machine Prototype} = 0.94 \times \text{Number of cutters} + 114.81 \times \text{Machining hour} + 0.11 \times \text{Number of dimensions} + 0.11. \tag{9}
\]

The total cost in Eq. (8) can now be expressed in more detail as

\[
\text{Total cost} = 7.6 \times \text{Number of cutters} + 870.68 \times \text{Machining hour} + 0.22 \times \text{Part length} + 1.57 \times \text{Number of setups} + 0.29 \times \text{Number of dimensions} + 2.04 \times \text{Machining time}.
\]

This cost is found by replacing the Machine Prototype activity in Table 4, with more detailed description of Table 7. These costs are added to Eq. (8). This detailed view of the activities allows much better tracking of cost, value-added and non-value-added activities and the resources’ usage and efficiencies.

6. Summary

Modern manufacturing operations face global competition on time to market, cost and product quality, among other issues. With product life span constantly shrinking, the design and development phases become more prominent, and under the need to be better controlled.

Traditional cost estimation methods proved to be inaccurate in allocating overhead costs to products. The costs of the design and development phase are even harder to estimate, since this phase consists of many activities that are not directly linked to the finished product.

This paper presents a modified ABC method that finds the cost of the design and development phase. The method is demonstrated using a sample part that is produced in a shop specialized in product development (one of a kind production).

The method presented is based on a detailed analysis of the activities that participate in the design and development phase. These activities are modeled using the IDEF0 convention. The cost of the product is found using activity cost drivers consumed by the product. The activities' cost-drivers rates are found using cost centers that directly serve those activities. The cost centers in turn are loaded with the direct and indirect costs of the whole facility.

The methodology is demonstrated and verified using sample rotational parts developed in a controlled manufacturing environment.

The method appears to be more accurate than the traditional cost estimation provided by the shop accountant. An additional advantage of the method presented is the ability to expand the costly activities and look in more detail at the causes of the cost. This can provide a valuable insight into the factors that cause the cost, helping to better manage these activities.

The methodology can be extended by using feature-based cost estimation in coordination
Fig. 4. Product development process.

Fig. 5. The design activity.
with ABC. This will allow designers to evaluate the cost of a product very early during the design stage based on committed geometrical properties.

**Appendix A. IDEF₀ modeling of selected activities**

The activities involved in the design and development of a product are modeled using

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**Fig. 6. Generating price quotations.**

**Fig. 7. The material handling activity.**
IDEF\textsubscript{0} diagrams. Figs. 4–8 present the corresponding IDEF\textsubscript{0} diagrams.

References


Merz, C.M., Hardy, A., 1993. ABC puts accountants on design team at HP. Management Accounting 75 (3), 22–27.
