INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
4 & 5 SEPTEMBER 2014, UNIVERSITY OF TWENTE, THE NETHERLANDS

COMPUTER AIDED COST ESTIMATING

Huub EHLHARDT
Faculty of Engineering Technology, Section of Product Design, University of Twente and Philips Innovation Services, Eindhoven, The Netherlands

ABSTRACT
Digitalization provides us with increasingly sophisticated tools, such as 3D CAD and ERP, that have become drivers of innovation in many industries. Traditionally, estimating product cost requires both craftsmanship as well as elaborative calculations. Product cost estimating practices are currently advancing with new digital approaches that, in this paper, are referred to as Computer Aided Cost Estimating (CACE) tools. CACE skill will give new engineers entering the manufacturing industry an edge, especially those in positions in which the cost of goods is an important aspect. This paper describes a new family of engineering tools referred to as CACE, elaborates on the use of cost estimating through the product lifecycle, and relates this to the educational context. The paper contemplates how CACE software might continue to develop and provides suggestions on how best to incorporate the development of CACE skills into engineering curricula.

Keywords: Cost engineering, cost estimation, Computer Aided Design, product lifecycle management, teaching software

1 INTRODUCTION

Since the advent of the personal computer a huge number of software applications have been introduced that have innovated the way we work. In the case of engineering, Computer Aided Design (CAD) has been developed as a core application since the end of the 1980s. CAD made the drawing board obsolete. More importantly, CAD made a host of new applications possible that further innovated engineering. Examples are Finite Elements Analysis (FEA), Product Lifecycle Management (PLM) and Computer Aided Manufacturing (CAM). The FEA software family provides applications that calculate and or optimize issues in domains such as strength and stiffness, plastic injection moulding or magnetic fields. PLM software is used to manage data throughout the product lifecycle like drawing numbers, Bill of Materials and engineering changes. The CAM software family enables applications such as Computer Numerical Controlled (CNC) milling and Rapid Prototyping. The wide variety of software used, also referred to as application landscape, has become indispensable for the operation of modern manufacturing industry and is set to continue driving change.
One of the new software applications for engineering that is currently gaining ground is related to the calculation of cost associated with the production of goods, also referred to as product cost estimation (PCE). In discrete manufacturing industries, cost engineers are using home-grown templates based on Microsoft (MS) Excel and or Access to calculate the cost of manufactured goods. Various consulting firms have developed slick versions of such templates, often linked to extensive databases with machine and labour rates. Various software vendors have developed more advanced PCE software. No generic name for this type of software has been adopted yet, although its use is currently gaining ground in discrete manufacturing industries. This paper refers to this family of applications as Computer Aided Cost Engineering or Computer Aided Cost Estimating (CACE) software. Various approaches to CACE are available in the market. There are currently no set standards for CACE software, either in cost calculation approach, user-interface or features, or in interfaces with other applications (CAD, PLM, ERP). The use of CACE software is not yet common practice throughout the manufacturing industry. There are many vendors from different backgrounds. It would appear that a dominant design for CACE software has not yet been established. Given the expected further digitalization of tools, it is likely that CACE will continue to develop and become part of the application landscape catering for functions involved in the development and production of goods (see

also Figure 1). This paper explores this new family of CACE software and discusses how it can be embedded in engineering curricula.

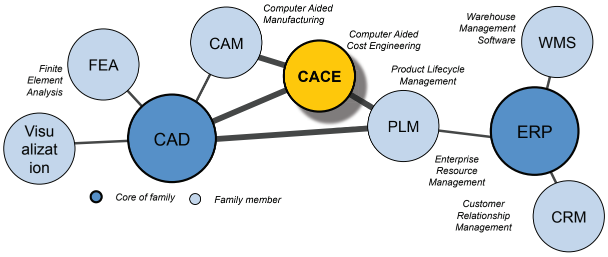

Figure 1. CACE in a landscape of applications used by the manufacturing industry

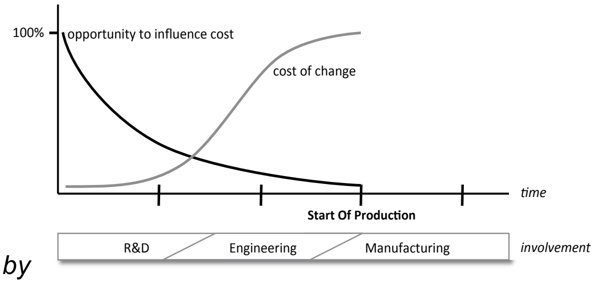

Figure 2. Costing through the Product Life Cycle

2 ESTIMATING COST

There is no single right way of estimating cost. Depending on the position in the product lifecycle or the value chain, PCE has different objectives. Different perspectives and industry characteristics have led to numerous different approaches to PCE.

2.1 Use of PCE throughout the product lifecycle

Diagrams like Figure 2 are often used to show how 'the opportunity to influence' cost rapidly decreases as development progresses. In the early stages of research & development (R&D), the accuracy of a cost estimate is not that high as designs are not yet fixed and many uncertainties remain. The function of PCE here is mainly to identify cost drivers in order to support decisions on architecture, materials and or manufacturing technologies. Once a product specification has been set, the opportunity to influence cost rapidly decreases. For that reason it is relevant to understand the cost structure early on in development, as the influence on cost is highest here, and cost invoked by change is lowest.

During the engineering phases, the product design is further detailed en route to a final stage where the design is frozen and drawings are further detailed to enable the ordering of tooling required for production. Once tooling starts to be ordered, the cost of changing a design increases dramatically. At the end of this phase, the opportunity to influence the cost via the design is reduced to zero. Cost estimates are used in this phase to support decision-making between alternative solutions for constructive details and therefore a higher level of accuracy is required than in R&D. During the engineering phase, 'make-or-buy' decisions are made. Many so-called head-tail companies outsource the production of components and/or assemblies to specialized suppliers.

Towards Start of Production (SOP) the required accuracy of PCE is highest. Outsourcing production to suppliers requires purchasers who negotiate on the cost of manufactured goods. In order to negotiate meaningfully, a purchaser needs to know what a product should cost. For this purpose highly accurate cost estimates are required. These are commonly provided by cost engineers. After SOP the opportunity to influence cost is low. Commercial negotiation or moving production to regions with lower labour costs is the most commonly-used method. Alternatively, the product can be redesigned, which effectively means a new version of the product that has to go through a development cycle all over again.

On the side of the supplier, the required accuracy of PCE is also high. After all, if the goods they manufacture are sold for less than the cost incurred when manufacturing them, a loss-making situation will arise. Suppliers therefore employ so-called estimators to calculate the cost of manufacturing goods in order to prepare quotes.

2.2 Methods and techniques for Product Cost Estimation

A large number of methods can be used to estimate the cost of products. An extensive overview of PCE techniques and methodologies is provided in [1]. This article describes no fewer than 12 different PCE techniques and classifies these, according to their approach, as quantitative or qualitative. The qualitative techniques are primarily based on comparisons of similarities between new and existing products. The quantitative techniques are based on a detailed analysis of products and manufacturing processes used. Each of the techniques has its own key advantages as well as limitations. A prominent quantitative technique which is discussed in more detail in this paper is Activity Based Costing

(ABC). The ABC methodology focuses on cost allocation and helps to segregate fixed costs, variable costs and overhead costs. The article does not elaborate on cost estimating software. However, it describes a group of Decision Support Systems that comprise rule based, fuzzy logic and expert systems which it classifies under the qualitative techniques.

The use of software to support PCE is discussed in an article by Micro Estimating Systems [2]. Three strategies are described, namely standards-based, engineering-based and intelligent emulation. The standards-based strategy uses a library of standards for particular manufacturing operations and assigns these to estimate cost. The engineering-based strategies use formulas to calculate the amount of time it takes to execute a particular manufacturing operation, also referred to as cycle time. The standards-based and engineering-based strategies require expert knowledge in the estimator to decide what type of machine and settings need to be used for particular operations. The article underlines the importance of using the right assumptions to derive the cycle time for particular manufacturing operations, as it is one of the key drivers of manufacturing cost. Obviously, the level of expertise of the estimator has a major influence on the accuracy of the cost estimate produced. The engineering-based strategy would be classified in [1] as an ABC method. The third method, intelligent emulation, applies algorithms to emulate manufacturing process to derive accurate estimates of cycle times. Examples of these algorithms are also found in CAM software used to program CNC machines or FEM software like Moldflow used to emulate injection moulding.

3 CACE SOFTWARE

With the advance of computing in the manufacturing industry software used to estimate product cost also became available. Academics have described [3] how they developed a system this paper refers to as CACE software. Vendors are now offering various types of CACE software and applying different levels of automation and approaches influenced by their background. No classification has been developed so far for the different approaches used in CACE software. Several vendors adhere to the ABC method. Others have developed software that reads 3D CAD files and automates a large part of the PCE process. As [1] and [2] do not provide an unambiguous classification for this automated type, they are referred to here as automated cost estimation (ACE).

The ABC types may be based on templates in MS Excel or Access as also used in dedicated environments. In general the ABC-type programs are very flexible in the type of manufacturing operations and complexity of products they can provide PCE for. The software operator can add machine types and assign investment levels as well as figures for the consumption of energy, consumables, required space and maintenance. The software automatically derives a tariff for use of the particular equipment per unit of time. The operator configures a calculation by selecting the type and amount of material used, the equipment to be used and then provides all the process parameters (such as cycle time, batch-volumes, set-up time, amount of operators, scrap level etc.) as input as well as levels of overhead associated with a particular type of manufacturer. This enables the costs to be modelled of virtually any (manufacturing) process and is as accurate as the input provided. In general, the ABC approach is known to be time-consuming and requires a significant level of expertise to use.

The ACE types that have so far focused on PCE for metals and plastics commonly use 3D CAD information as input. In these programs, the user has to select a small set of variables, namely material type, type of manufacturing operation and annual or batch volumes. Based on the settings and the information provided in the CAD file, ACE types derive an optimal manufacturing path and process times by emulation. Various approaches to ACE-type systems are available. Some ACE types can provide information on the cost of features (such as a particular radius) and so help to identify cost drivers and or suggest improvements to design engineers that reduce costs. The costing of electronics can be approached using ABC-type costing tools. Cost of Printed Circuit Boards (PCBs) is driven by the cost of components used. Commonly list prices are used for such components, which require up-to-date references (price erosion, obsolescence) and depend heavily on purchasing volumes.

Both ABC and ACE types provide tools to present or visualize results as well as tools to analyse the effect of different manufacturing strategies in relation to production volumes.

Although PCE appears to become simple with the availability of ACE-type software, it should be noted that, as with any type of software used for analytical purposes, the quality of information used as input defines the quality of the output. This observation is generally applicable in computer sciences and is often rephrased as ‘garbage in, garbage out’ (GIGO). Practically this means that an experienced user continues to be required for the successful operation of CACE software, both to incorporate

meaningful data into the software, as well as to interpret results in order to filter useless output. In general, ABC-type costing is more sensitive to GIGO than the ACE types, as ABC types require more (manual) data input.
The main CACE applications available are (by vendor); aPriori (aPriori), Costimator (MTI Systems), Concurrent Costing (Boothroyd Dewhurst), Micro (Micro Estimating Systems), Perfect Costing (Siemens), SEER (Galorath) and SolidWorks Costing (Dassault). Four of these are briefly described below.

3.1 Example 1; Perfect Costing
Formerly known as Perfect ProCalc, the Perfect Costing software was brought to the market by Tsetinis, a consulting firm founded in 2000 that is primarily active in the German automotive industry. In 2012 Siemens PLM Software acquired Perfect ProCalc and integrated the costing software into their engineering software portfolio. As part of the integration, the user interface look and feel was adapted to Teamcentre, their PLM solution. Perfect Costing uses the ABC approach to analyse costs and is featured with an extensive database close to 300 production regions and over 3000 types of equipment for which it provides labour and machines rates. This database allows for swift evaluation of the cost effects of moving production from regions with high labour costs to those with lower ones. Perfect Costing provides some tools to calculate cycle time and allows the inclusion of documentation (e.g. 2D drawings, photographs and excel calculations) in calculations. Perfect Costing software is currently known to be used at one engineering school in Germany. Siemens is preparing an academic bundle.

3.2 Example 2; DFM Concurrent Costing
Boothroyd Dewhurst Inc., that has specialized in Design For Manufacturing and Assembly (DFMA) tools and services since 1983, is the vendor of the PCE tool DFM Concurrent Costing. It is a hybrid tool in the sense that it can produce cost estimates starting with importing 3D CAD data from which it derives calculation input, as well as by defining manufacturing operations completely via manual input. Concurrent Costing includes a library with a wide range of equipment for machining, moulding, electric and assembly operations. The software assumes a single region (USA) where manufacturing operations take place, although rates can be altered into figures common for other regions. Concurrent Costing is complementary to a Design For Assembly (DFA) tool by the same vendor. It is unknown if the software is currently being used at engineering schools.

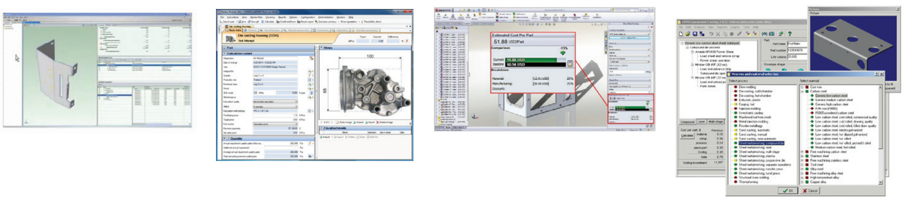

Figure 3. Screen shots of (left to right) aPriori, Perfect ProCalc, SolidWorks Costing, Concurrent Costing

3.3 Example 3; aPriori
aPriori, marketed by a company of the same name, requires 3D CAD data as input to start a cost estimate and is an ACE-type program. The focus of aPriori is on the costing of metals and plastics, including all kinds of surface treatments that are commonly used for these materials. aPriori does not allow automatic cost estimating for electrical parts like printed circuit board assemblies (PCBAs) as these are not described with 3D CAD. It uses so-called virtual production environments (VPEs) that cover labour, square meter cost and energy prices associated with the particular production location as well as typical overhead structures assigned to suppliers used. Standard aPriori offers a library of less than 10 VPEs, which means that it needs to be supplemented for all cases in which complex supply bases are used, covering multiple regions and suppliers to which different overhead cost structures are assigned. In an educational setting, aPriori software can be used in conjunction with training in CAD and (the design of) manufacturing subjects that support the development of an understanding of cost drivers in designs. aPriori is currently used in a few USA and UK based engineering courses. An e-book designed to use aPriori in design for manufacturing classes is currently being written.

3.4 Example 4; SolidWorks Costing

Dassault is the first major CAD vendor to integrate a costing solution as a module into its 3D CAD software. SolidWorks Costing allows design engineers to continuously check the design against cost. The automated cost estimate is updated as soon as a design is altered. The costing module only provides a cost estimate for sheet metal and machined parts and that significantly limits it use. Since 2012 the costing module has been part of the SolidWorks Education - and Student Edition. According to Dassault, over 28,000 licenses have been sold to schools, providing it with significant exposure to engineering students.

3.5 CACE outlook

CACE software is a family with no dominant design so far. As the manufacturing industry is a very cost competitive business, cost estimates will remain an important element, from R&D through to manufacturing. Consequently, the expectation is that the use of CACE will increase wherever it contributes to business competitiveness by making the PCE process more efficient and accurate. Ultimately the use of CACE will increase cost transparency and thereby influence the relations in supply chains.

Other types of software, like office and engineering applications, have clearly been evolving towards higher levels of sophistication and interoperability. Often, separate applications are bundled in software suits (like Microsoft Office), differentiated by level of complexity or sophistication (home versus business editions). Similar, CACE can be expected to evolve in level of sophistication (ease of use, accuracy, amount of processes covered) and with regard to integration into and or interfacing with other types of (engineering) software (e.g. CAD, PLM or ERP).

4 CACE IN AN EDUCATIONAL CONTEXT

Offering CACE to engineering students will help them develop an understanding of cost in designs produced. As such, it makes sense to contemplate embedding such tools in engineering courses. ACE-type costing software will be easier to use by students than the ABC types.

The manufacturing industry requires graduates to be familiar with modern engineering tools. CAD skills are obviously relevant for those entering design-engineering positions. Various authors [4], [5] wrote in this context on the use of other engineering applications. It became clear [6] that teaching complex high-end 3D CAD systems requires lengthy training. At the University of Twente, a course in Solid Works as part of a Bachelor's degree is assigned 4.5 European Credits (roughly 125 study hours). Many educational institutes only offer courses in mid-end applications of a lower complexity which are easier to teach. Once familiar with the user interface and conventions of a low or mid-end version of a CAD application, it is relatively easy to extend skills towards the more complex high-end versions. Educational institutes should therefore focus on making students familiar with the principles of engineering software tools using low or mid-end versions, rather than getting bogged down in teaching proficiency skills for overly complex high-end software.

Training in engineering software, such as CAD, using a traditional classroom method, requires expensive staff [6]. Online video-based training is an educational innovation currently gaining ground as a low-cost alternative to classroom teaching for students as well professionals. It is flexible in use, not bound by time or location and easily scalable for a larger audience. Teaching engineering applications using online video-based training offers the opportunity to increase the efficacy of educational processes. CAD vendors already provide online video-based training for their software. The expectation is that online video-based training will become the standard for CACE as well as it provides an efficient and flexible route to acquiring skills.

The available CACE software is maturing all the time. CAD software currently available is offered to different user segments. This might provide clues as to how CACE software can develop. Low complexity freeware versions with simple features are available for users with limited financial resources and/or minimal requirements. Demanding users can opt for expensive high-end solutions that integrate all types of applications. PTC offers a freeware CAD solution that enables the drawing of up to 60 parts in one drawing. Paid solutions by the same vendor offer more functionality but can cost more than ten thousand euros per user. Table 1 provides an overview of CAD applications arranged by complexity and cost level (or user segment).

In the case of CACE, no software portfolio strategies for use by CAD vendors have yet been developed. However, freeware versions of CACE software are already available via the web portals of

Additive Manufacturing suppliers. A quote can be generated simply by uploading a 3D CAD file and selecting a particular process, material and finishing. Hence, it is an example of automated cost estimation.

Table 1. 3D CAD applications arranged according to complexity and or typical cost level

Freeware (€ 0)	Mid-end (up to € 5,000)	High-end (€ 10,0000 and more)
PTC Creo Elements/Direct Modeling Express (PTC), FreeCAD (open source), OpenSCAD (open source)	Crea (PTC), SolidEdge (Siemens), SolidWorks (Dassault), Inventor (Autodesk)	Creo Parametric (PTC), NX (Siemens), CATIA (Dassault)

If CACE vendors choose to adhere to a similar strategy to CAD vendors, differentiation in their software could enable a range of users to be catered for. The availability of easy to use low or mid-end versions will allow students and professionals to acquire the skills needed to operate the software without going through a lengthy training process. This will undoubtedly stimulate the adoption of CACE software. Obviously, as far as engineering students are concerned, familiarity with the approach and user interface of simple versions of CACE software may prove a valuable skill on the labor market. Once they leave educational institutions, such familiarity with modern engineering software will guide new engineers into positions in which they can contribute to the further modernization of engineering professions.

5 CONCLUSION AND OUTLOOK

CACE is a new family of software used to produce product cost estimates. Embedding CACE in engineering curricula provides students with tools to analyze cost drivers. As such it increases the insight into the relationship between a design and the costs required to manufacture it.
CACE software will increase the speed and accuracy of PCE. As such the expectation is that its use will increase throughout the manufacturing industry. No dominant design or approach for CACE has yet been set. Vendors of CACE have not yet developed variants for different types of users.
Cost estimating continues to be a crucial element in development processes as well in outsourcing. Outsourcing and supplying manufacturers alike will need employees with the digital skills required to operate their modern cost estimating tools. They expect students leaving engineering schools to possess these skills. Consequently, exposing engineering students to CACE software will provide them with valuable skills and help them succeed in the labour market.

REFERENCES

[1] Niazi, A., Dai, J. S., Balabani, S., and Seneviratne, L. Product cost estimation: Technique classification and methodology review. *Journal of manufacturing science and engineering*, 2006, 128(2), 563-575.

[2] Micro Estimating Systems. *What is Computer Aided Estimating?* Available: http://www.microest.com/articles/WhatIsCAE.pdf. [Accessed 2013, 17 January]

[3] Shehab, E., and Abdalla, H. An intelligent knowledge-based system for product cost modelling. *The international journal of advanced manufacturing technology*, 2002, 19(1), 49-65.

[4] Berger, A. L., Brenzing, A. B., Feldhusen, J. The potential of low cost topology optimization, 2013, (*International Conference on Engineering and Product Design Education*, Sept 2013, Dublin Institute of Technology, Dublin, Ireland).

[5] Barrie, J., Owen, G. Exploring featherweight industry PLM solutions for academic use, 2013, (*International Conference on Engineering and Product Design Education*, Sept 2013, Dublin Institute of Technology, Dublin, Ireland).

[6] Aasland, K. Individual study of 3D modelling software using interactive video, 2013 (*International Conference on Engineering and Product Design Education*, Sept 2013, Dublin Institute of Technology, Dublin, Ireland).