Life Cycle Cost Estimation Tool for Decision-Making in the Early Phases of the Design Process

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Abstract

Design is a process that involves information processing and decision-making. As cost is an important factor that must be considered in the decision-making at this phase, proper information about costs is extremely important for designers. The authors present a cost model and tool developed to help designers estimate the life cycle cost of their products and to permit them to make more cost-effective design decisions. The tool can be used in a concurrent engineering environment to provide cost estimates for different design alternatives. What-if analyses can be performed to compare costs when using different components, materials or manufacturing processes.

Keywords:

Life cycle cost estimation; cost model; DFE (Design for Environment) tool

1 INTRODUCTION

Typically, product designers make their design decisions based on a product's technical and functional features. From the designer's point of view the most important criteria for products are quality, durability, performance and conformance with the customer's specifications [1].

Recently, additional criteria have become important in the decision-making process at the design stage; for example the life cycle impact on the environment is now very important because of standards [2, 3] and legislative requirements [4].

An approach to integrated design of products and related processes is concurrent engineering (or integrated product development) [5], which makes designers consider in the design process all elements of the product life cycle from raw materials extraction through manufacturing to end of life.

The primary goal of concurrent engineering is the minimisation of product costs while maximising its quality and performance [6]. This simultaneous approach to product development – concurrent engineering – can offer opportunities to embed cost performance in the design process.

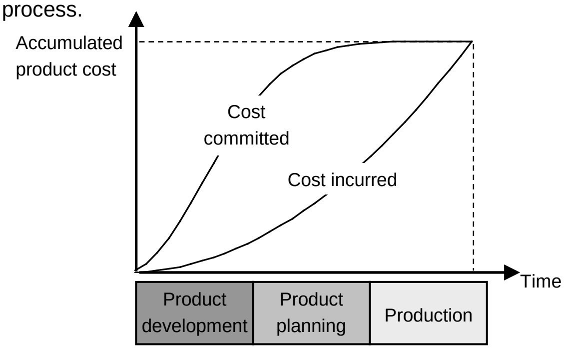

Figure 1: Product development and costs [9].

It is well-known that 70-80% of the production cost is committed at the early design phase [7, 8] (see Figure 1). Efficient cost management recommends that costs be controlled when committed, or else they cannot be minimised afterwards [9]. Therefore, unnecessary product costs must be eliminated in the commitment stage [10].

In addition to the production costs, a large proportion of the costs of the use and end of life phases are also committed during product development. The estimation of these costs early in the design stage is important because they represent a competitive factor, a differentiation in selecting a product.

In order to be able to use cost as a decision criterion in the design phase, one must be able to measure the costs of product's life cycle stages. As costs are not known in advance, a cost estimation system is necessary to generate the required information [11].

This paper presents a cost estimation model based on the Activity-Based Costing (ABC) methodology and other costing techniques for use in life cycle design. The model combines both product and process aspects which are necessary for the calculations (sections 2 and 3 discuss the product and the process models). The cost model is presented in detail in section 4. Section 5 shows how the cost model is integrated as a module within the DFE (Design for Environment) Workbench software tool.

The purpose of the tool is to enable different design configurations (different materials, different components, different processes) to be compared not only from an environmental compliance view but also from a cost perspective. The tool offers support in the decision-making process at the early phases of the design process. The inclusion of cost permits more informed business decisions and considerations to be undertaken by the designer.

2 THE PRODUCT MODEL

The product model follows the STEP standard (Standard for the Exchange of Product Model Data) [12]. It supports an object-oriented representation easy to integrate with a PDM and various CAD systems (e.g. Catia, Pro-Engineer). The product model provides information necessary for cost estimations and for calculating the impact on the environment over its life cycle. The information contained in the product model, briefly presented in Figure 2, is:

- Hierarchical product structure (sub-assemblies, components, parts).
- Identification data for product, sub-systems, purchased items, suppliers, materials.
- Materials information, properties associated with materials.
- Geometric data, dimensions, weight.
- Information relating the part to the adjoining components in an assembly (fasteners).
- Package data.
- Manufacturing information (process data).
- Financial data.
- Data pertaining to any life cycle phase of the product/sub-system.

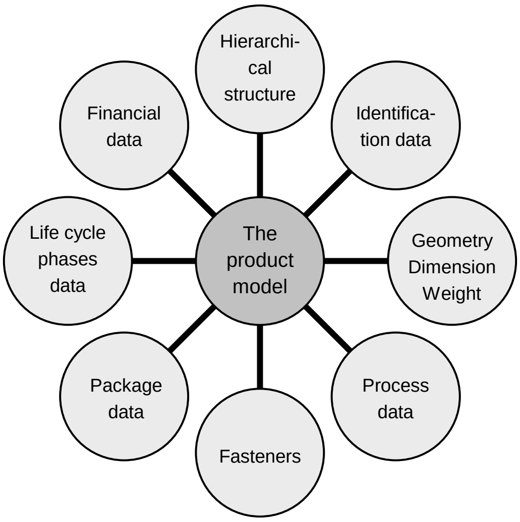

Figure 2. Content of the product model.

The STEP model was chosen because it supports integration with CAD and it permits integration of data as a total product model supporting many different users.

3 THE PROCESS MODEL

A process model was developed to support the cost calculation for the manufacturing phase of the product's life cycle.

The process model is driven by two groups of data. The first group, *process input data*, consists of data related to external inputs to the process (e.g. components, materials), and the second group, *specific process data*, contains internal data that characterise the process (e.g. lot size). A structured IDEF0 [13] graphical representation of the model is presented in Figure 3.

The data related to external inputs to the process include:

- Components, sub-assemblies with all the information associated to them as described in the product model (see Section 2).
- Direct materials.
- Consumables.
- Direct labour.

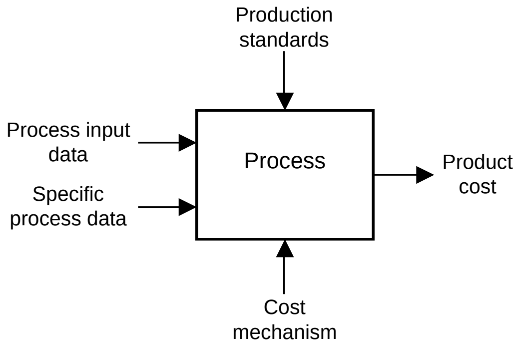

Figure 3. The process model.

Internal data specific to the process are also necessary for the cost calculation, such as:

- Process (activity) driver.
- Batch information (e.g. lot size).
- Scrap and rework.
- Waste.

The development of the process model as presented in Figure 3 was intended to support the use of ABC for calculating the manufacturing cost of a product.

4 THE COST MODEL

The cost estimation tool is intended to support designers in the decision-making process by giving indications of the individual life cycle stages costs (e.g. manufacturing) and the overall life cycle cost of the product so that comparisons of design alternatives at the early stages of the design process can be made.

4.1 The cost structure

In order to permit comparisons on an individual life cycle stage cost basis as well as on a total life cycle cost basis, various costs associated with the product life cycle (see Figure 4) are defined:

- *Manufacturing cost* – is the most important for the manufacturer. It comprises costs such as the raw materials cost and the actual production cost.
- *Environmental cost* – is the indirect cost of the manufacturing company which is related to the environment. It is important to see how changes in design can affect different elements of the environmental cost (such as package cost, waste disposal cost or licences and fees).
- *Use/operation cost* – costs like the repair/maintenance cost or the energy or fuel cost (depending on the type of product) are included in this category.
- *Retirement and disposal cost* – this component of the life cycle cost becomes important for the designer especially in the context of recent legislation (e.g. ELV Directive, WEEE Directive, Integrated Product Policy (IPP) [4]).

The cost model considers the classification of costs into *direct costs* and *indirect costs*. Direct costs can be allocated directly to the cost object (the product). Indirect costs cannot be allocated directly to a cost object; they are collected in cost centres and subsequently allocated to cost objects.

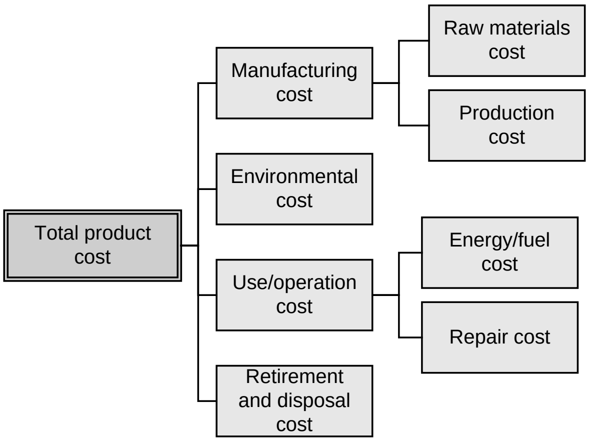

Figure 4. The cost breakdown structure.

4.2 The cost calculation

To effectively compare alternatives, the designer must be able to accurately estimate costs for the complete system so that 'what if' scenarios can be built. The costing information is derived from the description of the product and its components (see Section 2), and from the description of the processes the product/components are subjected to (see Section 3).

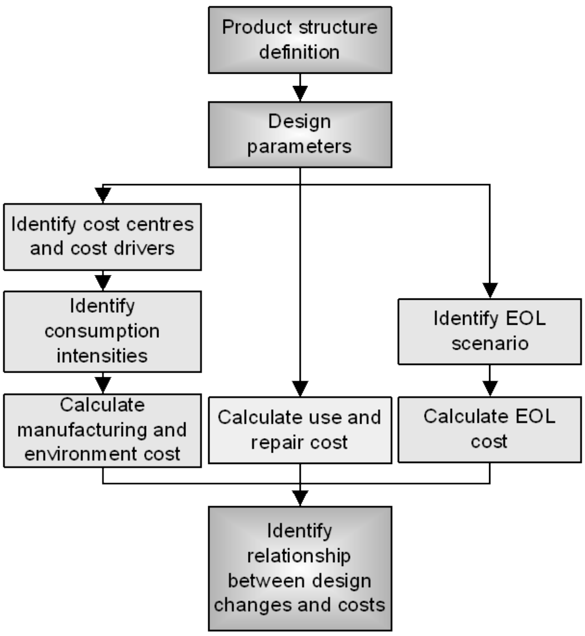

Figure 5. The cost model.

The cost model is a combination of life cycle costing (LCC) [10], feature-based costing and activity-based costing (ABC) [10]. As the majority of the costs considered in the model are future costs, their present value is calculated using an appropriate discount rate. The cost model aims to give the designer a complete picture of the product cost and to show the influence of different changes in the design on the total cost of the product as well as on different elements of the cost. The cost calculation follows the steps presented in Figure 5.

The manufacturing cost

The manufacturing cost model uses the product decomposition as described by the product model. For bought-in components only attributes which describe the product are considered (i.e. mass, dimensions). Meanwhile, for manufactured components the variables which describe the product *and* those which describe the processes through which they go are considered. Thus, the cost model is based on the link between the design parameters (product's elements' attributes) and the manufacturing processes.

The raw materials cost included in the manufacturing cost is shown separately. Raw materials cost is direct cost and can be traced directly to the product. The direct costs category also includes consumables cost and direct labour cost.

The overhead is traced to the final product using the ABC method [8, 10] which follows the following steps:

1. Identify the indirect costs (resources).
2. Choose each resource driver.
3. Calculate the annual resource rate.
4. Break up the processes into activities and build the activities hierarchy.
5. Identify the amount of resource drivers consumed by each activity.
6. Calculate the total activity cost.
7. Choose each activity driver.
8. Calculate the consumption intensity (the unit price of a driver unit).
9. Calculate the overhead cost per product.

The R&D cost is considered part of manufacturer's cost; therefore the model includes this cost in the overhead.

The methodology is extended by using feature-based cost estimation in coordination with ABC (consumption of cost centres depends on the design parameters). This allows the designer to evaluate the product cost based on physical properties very early during the product design stage.

The environmental cost

The environmental cost is actually an overhead. It is treated separately, although it follows the same ABC methodology, because it is important to be traced to the product separately in order to see the influence of design changes on this cost category.

The model takes into consideration only the internal environmental costs related to the product, which represent environmental costs that have a direct financial impact on the company (such as waste treatment cost, labelling cost, licence and permit fees, prevention and environmental management cost, fines and penalties).

The use/operation cost

The costs categories considered in the cost model for the use/operation phase are repair/maintenance cost and energy/fuel cost. Design parameters such as Mean Time to Failure (MTTF) for unrepairable components and Mean Time Between Failures (MTBF) for repairable components are considered in the repair cost model. Depending on the type of product (energy consuming or fuel consuming), energy cost or fuel cost is modelled for the entire product lifetime.

The retirement and disposal cost

An end of life (EOL) option is defined for each component of the product and costs associated to that particular option are modelled.

4.3 The outputs of the model

The outputs of the model are:

- A summary of the costs necessary to produce, use and dispose the product. This information is shown per product and per component and is broken down into: total life cycle cost, manufacturing cost, labour cost, materials cost, component cost, consumables cost, recycling cost, disposal cost.
- A graphical representation of the product cost of each life cycle stage that permits the designer to see at which stage improvements should be made.
- A graphical representation of the components' costs. This will show a hierarchy of costs and the designer will be able to see which component is the most cost-effective and which needs re-design.

5 THE SOFTWARE – INTEGRATION OF THE COST MODEL INTO THE DFE WORKBENCH

The cost model presented in the previous section was integrated as a cost module into the existing DFE Workbench which will be briefly presented below.

5.1 The DFE workbench

The DFE Workbench [14, 15] is a design for environment software tool integrated into a CAD environment (Pro Engineer 2001, Solid Works 2000, Catia V5 R16). It has been developed to assist and advise the designer in the development of environmental superior and compliant products in order to meet the requirements of the latest legislation related to environment and customers' needs.

The DFE Workbench consists of the following modules (see Figure 6) [14, 15]:

- The Impact Assessment System (IAS).
- The Structure Assessment Method (SAM).
- The Advisor Agent.
- The Knowledge Agent.
- The Report Generator.

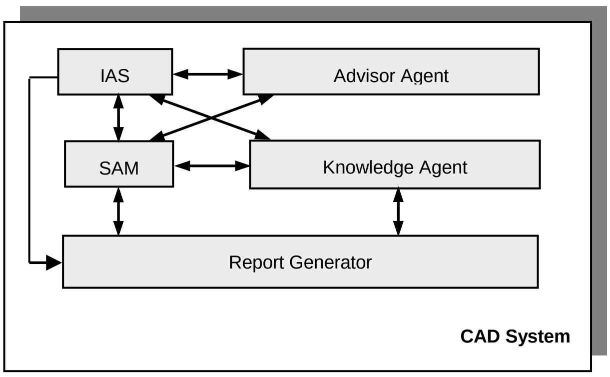

Figure 6. The DFE Workbench structure [14, 15].

The *Impact Assessment System (IAS)* is an abridged quantitative approach to LCA, performing synthesis, evaluation, prioritisation and improvement of environmental data. Environmental impact can be calculated for the entire product or for each of its components.

The *Structure Assessment Method (SAM)* is a complex methodology, which quantitatively measures and records data such as material compatibility/substitution (taking into account fasteners), components' serviceability, number and types of fasteners, number and types of tools required for disassembly and total standard disassembly times and component removal times.

The *Advisor Agent* has two functions: firstly to prioritise variables generated by the IAS and SAM tools; secondly to give advice to the designer on alternative structural characteristics in order to enhance either the environmental impact or structural characteristics of the emergent design.

The *Knowledge Agent* provides advice to the designer in a consultative mode. For example, the designer can use the Knowledge Agent to find a material with specific mechanical and environmental properties and then use the selected material in the design process.

The *Report Generator* automatically generates reports on the product designed by the user.

5.2 The integrated software tool

The cost estimation model was integrated within the DFE Workbench (see Figure 7), thus permitting a comprehensive overview of the environmental impact and associated cost of a product over its entire life cycle and offering a real support to decision-making at the early design phase.

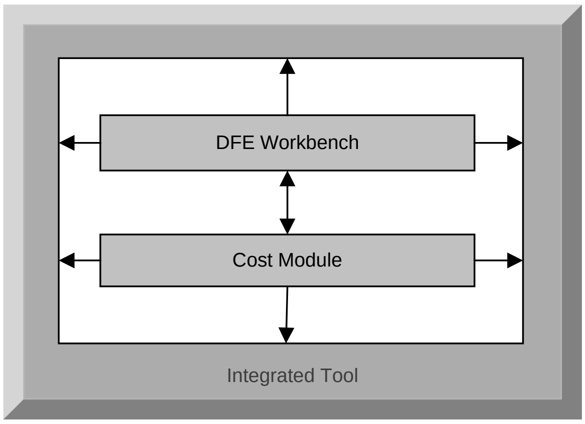

Figure 7. The integrated tool.

The integrated tool system provides a database and management software that permits the collection and analysis of information related to product, processes, end of life, suppliers and cost records. Figure 8 shows the data flow from different company's departments which are potential providers of data (e.g. designers, accountants, environmental manager, manufacturing engineers) into the database (solid arrows).

This information is processed to calculate the product costs and the environmental impact, which are of great potential value for designers, as well as for the environmental manager or the accounting department. In Figure 8 dashed arrows show the flow of information from database to the potential users (designers, environmental manager and accountancy).

'What if' scenarios can be built by considering various design configurations and, based on the information offered by the tool, decisions can be made. The tool is not meant to replace the decision-making process itself, but to offer support to the decision-makers.

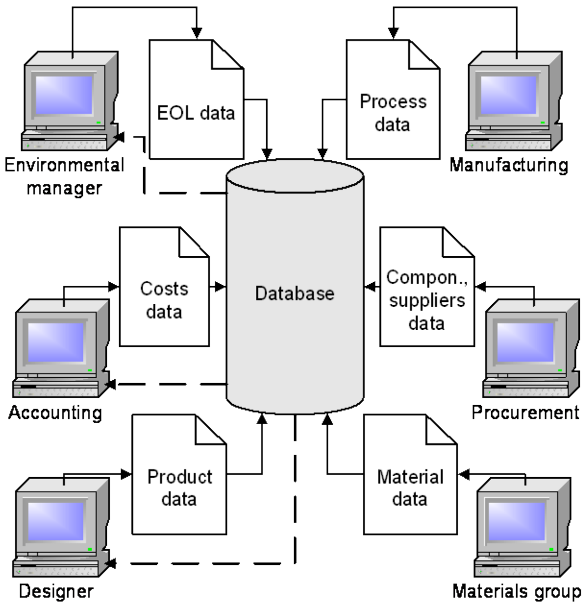

Figure 8. The integrated system structure.

6 CONCLUSIONS

The life cycle cost estimation tool integrated with the DFE Workbench offers a powerful decision-support tool to designers in the early phases of product development.

The system provides results like costs and environmental impact at product level or component level in the context of the full life cycle of the product, thus offering a solid base for decision-making to the product designer when it comes to producing environmentally-compliant products in a cost-effective manner.

It should be noted that the tool is currently under further development. In the future a case study will be carried out for test and validation of the model, and for collection of data necessary to populate the database.

7 ACKNOWLEDGMENTS

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