An Activity-Based Cost Model for Design-Concurrent Calculation

by

Dirk Wiegmann

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Industrial and Systems Engineering

APPROVED:

William G. Sullivan

William G. Sullivan

Larry N. Killough

Roderick J. Reasor

May 1992

Blacksburg, Virginia

An Activity-Based Cost Model for Design-Concurrent Calculation

by

Dirk Wiegmann

William G. Sullivan, Chairman

(ABSTRACT)

This research develops the concepts as well as a "case study" implementation of a cost model that estimates the costs of product design alternatives during the design process. This cost information, regarding design alternatives, is for decision making purposes. With the help of this cost model, the designer can better approximate that product form which results in the lowest costs of production, i.e., for which the sum of material costs and activity costs are minimized.

The cost model integrates similarity analysis into an enhanced version of an activity-based cost management system. The similarity analysis is required because the details of a product's bill of materials and bill of activities are not yet available during the design process; however, such information provides the basis for any activity-based cost calculation.

In a first step the cost model determines which of the existing products, based upon their cost driving characteristics, belong to the same product family as the design alternative. For these products detailed information is available, thus they can be used as reference products for the similarity analysis. These existing products are calculated as if they were the design alternative, hence they follow the decision costs principle; i.e., costs that will appear in the future but were determined in the past are not relevant for a

particular decision. Subsequently, those reference products - as calculated on the basis of decision costs for the respective design - are utilized in a regression analysis. This analysis approximates the functional relationship between the product's cost driving characteristics and its costs, so that, finally, the costs for the design alternative in question can be estimated based on its characteristics.

Acknowledgements

I would like to thank Professor William G. Sullivan who not only served as chairman on my committee but also provided crucial expertise in the execution of this thesis. His insights in the current issues of strategic cost management and concurrent engineering had guided me towards the area of interest and were supportive throughout the entire research. Furthermore, he spent significant amounts of time reviewing and revising the document, thereby contributing considerably in the write-up of the final document.

I thank Dr. Larry N. Killough and Dr. Roderick J. Reasor for also serving on my committee. Their critical suggestions and ideas were most helpful and certainly strengthened the results of my work.

Table of Contents

Chapter 1:

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

List of Tables

List of Figures

Chapter 1

INTRODUCTION

Motivation

Design is the first phase in the life cycle of every product. Consequently, decisions made in the design stage have the greatest possible leverage to influence the product's quality, performance, and profitability throughout its entire life cycle.

While several surveys have shown that over 70% of a product's cost are determined in the design phase, most companies still focus on improving the production process in their struggle for competitiveness. However, because process planning determines only around 20% of the product's cost, the potential for significant cost reductions from this approach is limited. On the other hand, improvements in the product design offer significantly more cost leverage. Overall, although the benefits from improved design might not be as obvious at first because of their long-term nature, it is this long-term characteristic that makes the design phase so critical.

In what is considered a benchmark survey regarding design literature Ehrlenspiel [EHR80] in 1980 evaluated the cost reductions achieved by value engineering of existing products. The survey covered 135 products and 42 companies with the majority being large companies from the machine building, vehicle, and precision engineering industry. The products the companies had analyzed were predominantly manufactured in large quantities with an average life cycle of 7 years.

One observation was that the cost of production could be reduced through value engineering by between 10% and 80%, but on the average by 33% (see Figure 1-1).

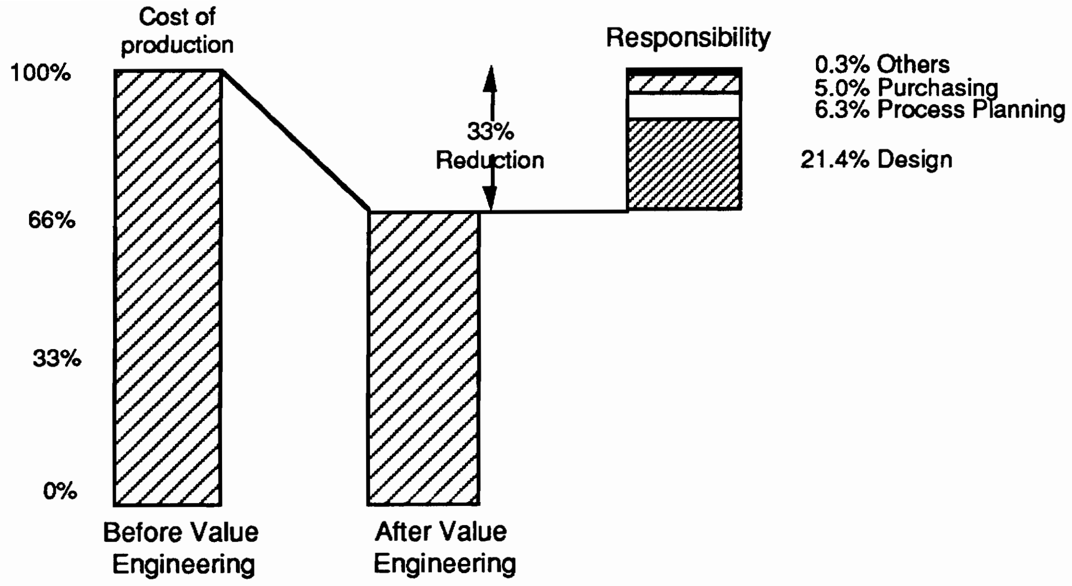


Figure 1-1: High costs caused by inefficient design [EHR80]

Most important, however, was the fact that the product design had been responsible for the clear majority of the changes that were made to reduce the cost of production. On the average as much as 67% of the cost reduction was achieved only by changing an initially inefficient design. The major changes that were necessary and that proved to be designers' responsibility were the following:

- introduction of part families and norm parts
- use of a different design concept
- reducing the number of parts
- combination of parts and separation of complex parts
- use of less expensive manufacturing processes
- redesign for manufacturability
- use of different material.

The fact that more than a 21% reduction in total cost of production was possible by only changing the product design shows that presently the designer frequently lacks accurate cost information when (s)he has to decide between design alternatives. Too often the designer cannot determine the least expensive design.

In his survey Ehrlenspiel also evaluated what cost information and other resources designers actually used in their design decision process (see Figure 1-2). In as much as 63% of all cases practitioners relied on cost calculation lists of current products in the design of a new product, whereas in 57% they relied on cost comparisons of material. Weight-based short calculation methods were used in 29% of the cases studied, estimation based on experience in 23%, and relative-cost factor catalogs in 14% of all designs. All of those resources used in the early phases of the design process have in common that they are largely based on product cost calculations from old designs.

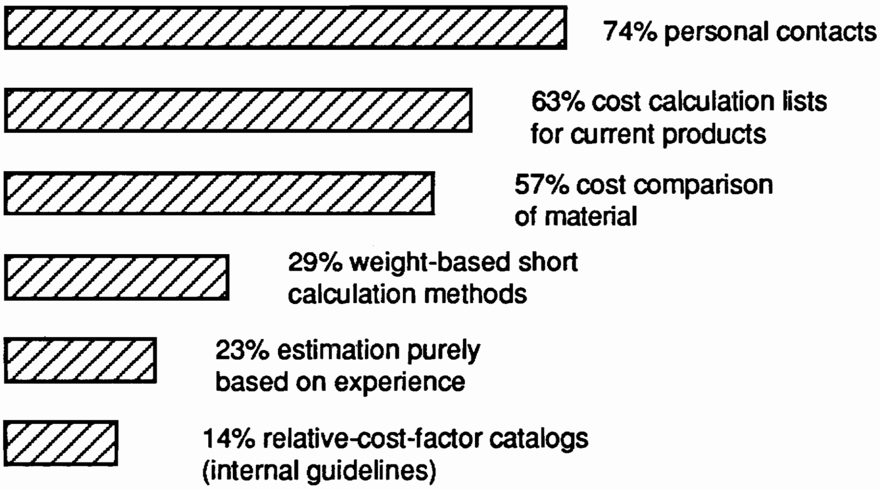


Figure 1-2: Cost information used in the design process [EHR80]

Product cost calculation

The problem which has led to most of the design inefficiencies discussed previously is that cost information for existing products tends to be very inaccurate, particularly when derived from traditional methods [CO88a], [HOR89], [KAP84], [KA90b]. Following a brief explanation of the inherent problems of traditional product cost calculation methods, a much improved activity-based cost system will be introduced to address this problem.

Traditional methods

Traditionally, the calculation of the product's total costs are based on process plans (e.g. cost of direct labor) and a bill of materials (cost of material), i.e., costs that can be allocated directly to each product. Other costs besides labor and materials cannot be attached to an individual product when using process plans and are treated as so-called "overhead costs." Overhead costs are generally assigned to products as a percentage of their direct costs (see Figure 1-3).

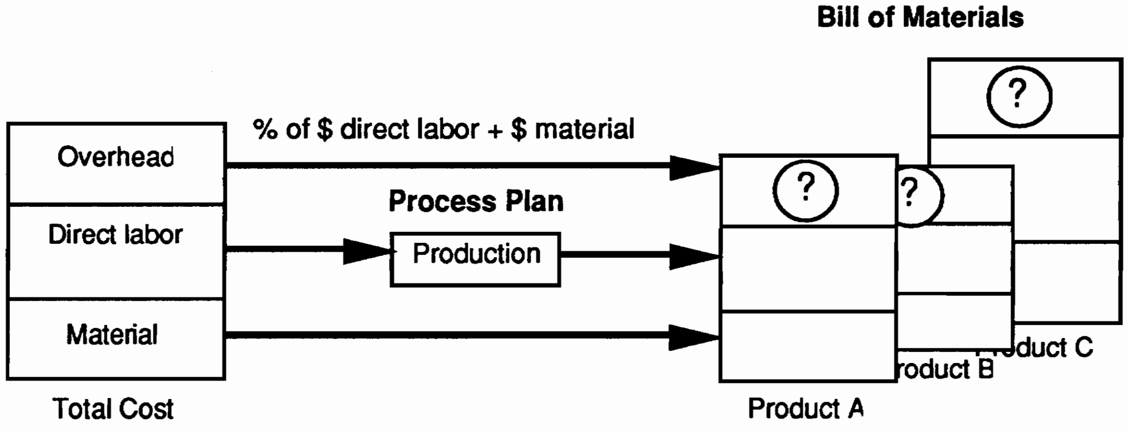


Figure 1-3: Volume-based product cost calculation

Thus, in such volume-based systems the amount of overhead costs, sometimes also called "hidden costs," that each product is responsible for solely depends on direct labor content and its material content. This key for allocation of indirect costs is inherently arbitrary and can, in consequence, easily lead to distorted product cost calculations and, by a similar argument, to poor design decisions.

This potential danger of the traditional cost allocation method is being made worse by increasing technological developments that have generally shifted the cost structure towards increased depreciation, data processing, and engineering costs. Resultant total overhead costs in the U.S. often reach 50%-70% of the product costs [BRI86], [MIL85].

The two fundamental mistakes in the traditional overhead cost allocation stem from the varying number of different overhead activities and from possible overhead economies of scale. Each is discussed below.

Number of different overhead activities

The production of a product requires manufacturing activities as well as overhead activities. However, only the manufacturing activities such as welding, lathing, forging, drilling, etc. are part of the process plan, while the whole variety of different overhead activities is not included. The costs of the latter are only added to the manufacturing activities in the form of percentages. One problem with this is that the same product might, dependent on its design, require a very different number of overhead activities. A design with many, separate parts might need many different overhead activities in the form of administration and material handling. A different design of the same product using those parts combined might cause significantly less overhead costs.

When using traditional cost calculation methods, overhead activities are accounted for based on direct costs, thus ignoring how the actual cost of overhead activities vary depending on different designs. In this cost environment a designer trying to decide on the most cost efficient design might inadvertently create new overhead activities and costs as they are not properly accounted for in his decision process.

Economies of scale

The traditional cost calculation of a product is performed independent from manufacturing quantity. However, due to economies of scale the larger the quantity produced the less cost per unit should usually be allocated to a product, and vice versa. While this economies of scale is well-known for manufacturing activities, Horvath and Renner [HOR90] among others have shown its significance for overhead activities. They analyzed a company with 21 variants of a single product line all having similar costs of material and manufacturing processes, i.e., resulting in the same product costs when applying the traditional, volume based cost methods. Their study showed that small quantity variants caused almost the same overhead costs as large quantity variants, or, in other words, once an overhead activity is caused its total cost is very insensitive to the quantity so that the costs per unit drop significantly with increased quantity (see Figure 1-4).

Thus, a design using existing parts and components will show no cost advantage over one using new and different parts, when the traditional cost calculation is followed. However, in reality designing around existing components greatly reduces total cost of production because the marginal cost for existing overhead activities tends to be small.

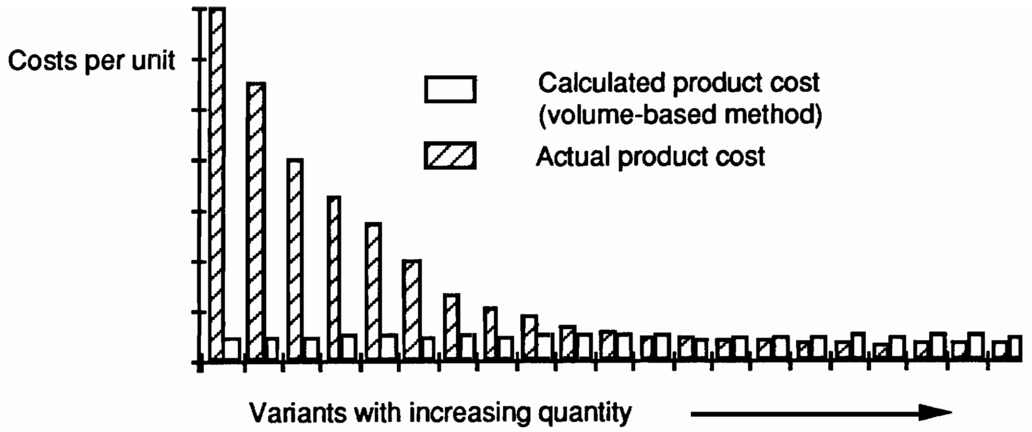


Figure 1-4: Economies of scale for overhead activities [HOR90]

Activity-based methods

By now, the above problems of traditional, volume-based methods are well understood in the literature. About seven years ago, leading American industrial and consulting companies, as well as universities started the Cost Management Systems (CMS) program, which can be considered the source of the Activity-based Cost Management approach [BER88]. By 1990 about 100 implementations of this cost management approach were counted worldwide [FRÖ91]. Although some comparable systems were known since before WWII, one of the main obstacles to further recognition have been the tax regulations which require the filing of financial reports according to the volume-based procedure [EBE90], [BOR90], [JO87a]. Also, in the past the drawbacks of traditional approaches have not been as critical because only over the last decade has the proportion of overhead costs increased drastically.

The starting point of the activity-based approach is the fact that the production of each product requires a variety of activities. Activities are all those operations performed within each business function. To determine what activities are performed on a product, its flow through the production process is observed carefully step by step, and all activities that influence the making of the product, even if only remotely, are recorded. The list of all these activities is called the bill of activities, which includes the manufacturing activities as well as all overhead activities. The bill of activities forms the focal point of the activity-based methods for product cost calculation. As the complexity of products increases, more overhead activities such as planning and controlling have to be performed as well. The bill of activities includes them all so that calculated product costs can correctly reflect the difficulty of making complex products.

The bill of activities not only includes the number of different overhead activities, but also takes their economies of scale for current products into account - the second major problem area not satisfactorily resolved by traditional systems, as outlined previously. For every activity a "cost driver" is determined. This cost driver should best reflect the cost influencing factor of the respective activity. Many different types of factors can be cost drivers including hours, units of products performed, or number of setups. The bill of activities includes how many cost drivers the product requires for its production while being a part of a whole production lot, thereby the bill of activities accounts for the economies of scale effect. This effect is important only for those activities whose cost drivers are independent of quantity, e.g. placing a purchase order. In this example, the cost driver in the bill of activities will be 1 for production lot size 1, and 0.01 for lot size 100. Horvath [HOR89] and Kaplan [KA89b] call these activities batch activities. They have in common that their cost driver is independent of quantity, i.e., variant driven. On the other hand activities with volume-driven cost drivers are called unit level activities. A third type of activities are called product sustaining activities. Their cost drivers are totally independent of production.

Another difference of the activity-based models compared to traditional ones is its functional organization of activities. In order to more easily trace the product during its production process, the cost management system groups activities into business functions. In such a functional model, like the one shown in Figure 1-5, the Material Management function, for example, would include all activities that are required to get the material into the company including purchasing, material receiving, supplier payments, debitor accounting. On the other hand, in traditional models the purchasing activities and the supplier payments are part of the administration whereas the material receiving activity is part of the shop floor. This different classification clearly reflects the different orientation of the systems; traditional systems are department oriented while in activity-based systems the product flow through the company is the center of consideration.

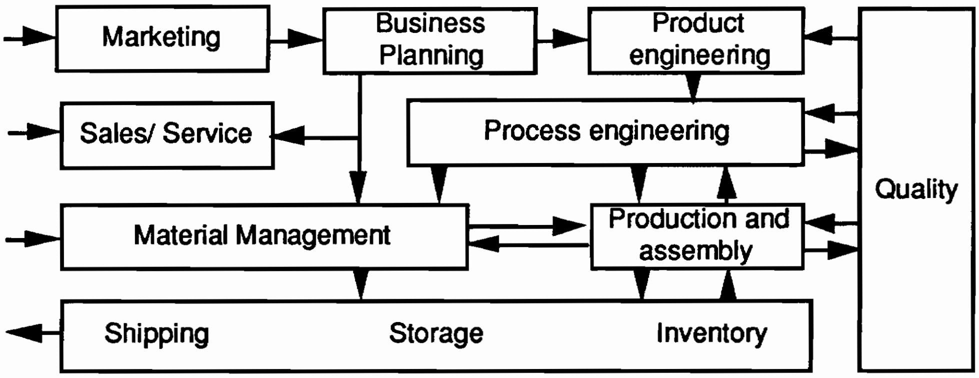


Figure 1-5: Functional diagram of manufacturing enterprise [FLA88]

One reason for why the CAM-I consortium has chosen the functional model approach for a cost system is that it better models the product flow. Then, by knowing the cost of each activity required in the production process of each product, the cost management can best control the costs of the products. Another reason for the functional grouping is its fit for the CIM factory [FLA88]. By giving the cost management system a similar structure as recommended for the CIM factory, the transition of data is simplified which is a necessary first step to computer integrated cost management [FRÖ91].

In summary, an activity-based cost system directly traces all costs to activities including the previously "hidden" overhead costs, while in traditional systems the direct cost allocation was limited to manufacturing processes, and there predominantly to labor costs. For the product cost calculation, the process plan shown in Figure 1-3 is expanded to the bill of activities for each product as shown in Figure 1-6.

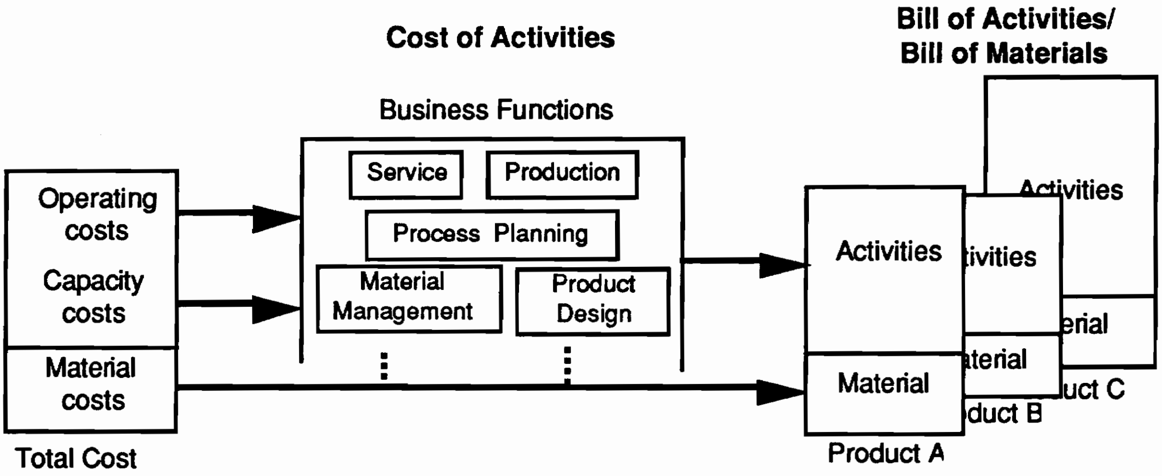


Figure 1-6: Activity-based product cost calculation

Overall, the activity-based approach can produce very accurate product cost calculations and, consequently, its information can be very valuable for the design process. Unfortunately, current activity-based cost management systems still lack some flexibility, as well as some additional analysis techniques, that limit the accuracy of product cost calculation specifically during the design process in the Design-Concurrent Calculation.

Design-concurrent calculation

Theory

The responsibility of the designer is to find a product form that not only satisfies given functional requirements but also one that minimizes the sum of activity costs and material costs of the product.

In theory, an activity-based method appears to be the ideal tool to find this cost minimum because it calculates production costs with such high accuracy. The idea is that the designer is provided with the most accurate production cost information so that (s)he can properly calculate the costs of various design alternatives and choose the best thereof. Thus, an activity-based method should be the basis for cost-efficient designing.

Classical design guidelines such as reduction in the number of parts, introducing less variants, reducing the number of required processes can then also be supported by cost rationale. In addition, at least in theory, the point can be determined at which, for example, further reductions in the number of parts would make them so complicated that higher cost for material, pre-production activities and manufacturing activities will offset the simplification advantage. Again, the goal is to find the right balance.

According to an international survey by A.T.Kearney, productivity can be improved by up to 40% when optimizing a design with respect to material and activities using an activity-based method [FRÖ91]. A comparable result cannot be obtained when using a volume-based method to support the design decisions because they only account accurately for a portion of the production costs, namely the process costs.

While the theory sounds appealing, one of the problems faced is that current activity-based cost systems cannot provide all cost information that are really needed in the design process. They cannot supply the information at the low detail level oftentimes required, and they also fail to supply only decision relevant costs. Both of these problem areas will now be explained briefly, and then this research proposes some solutions.

Practice

Detail level

The design process always starts on the lowest level of detail. During this phase only decisions for specific concepts of the final product are made. Later in the design process those concepts are refined in detail by dividing each concept into subgroups which, subsequently, are further subdivided to even higher levels of detail and so on. Thus, the design can be characterized as a top-down process, starting at a low level of detail and gradually moving to a high level of detail (see Figure 1-7).

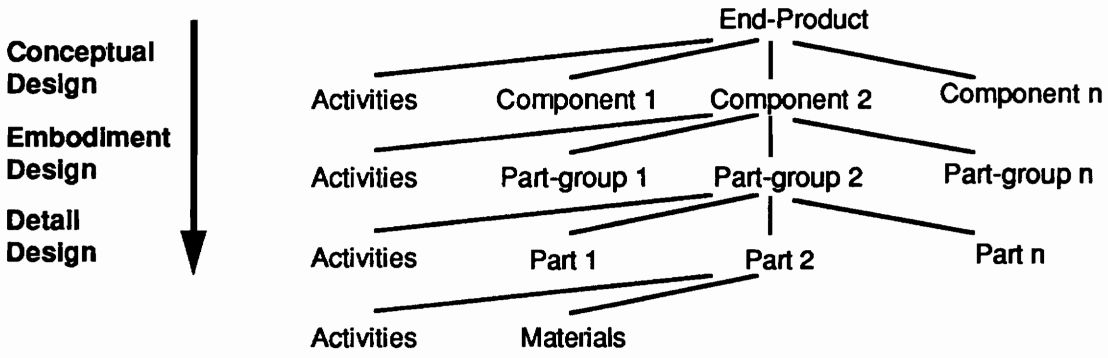


Figure 1-7: Increasing level of detail in the design process [BEC90, modified]

Once the design process has reached its highest level of detail the product has been broken up into small individual parts, each requiring material, manufacturing activities, as well as overhead activities. Manufacturing activities include welding, lathing, forging, drilling, i.e., activities performed on a shop floor, whereas overhead activities can be material handling, process planning, or product engineering.

In early stages of the design process, decisions are made at low levels of detail. Those decisions have significant cost leverage as they impact on a large number of activities. The later decisions are made in the design process the less activities are involved and, consequently, the smaller is the decisions' cost impact. Decisions at the level of parts or components only involve their respective activities, while decisions concerned with the end-product have to take the costs of all activities of all parts of the entire product into consideration.

Clearly, it is very desirable to be able to predict accurately the cost of alternative designs early in the design process, i.e., at low level of detail. However, while cost information is more critical early in the process, it also tends to be less accurate because it is so much more difficult for the designer to determine all necessary activities and materials and their associated costs at that low level of planning detail. Now, considering that costing alternative designs early in the process is critical at that point it seems impossible to determine all relevant activities and materials and their respective costs.

One technique to obtain cost information at the detail level in question and one that can be applied for design-concurrent calculation is using cost information from existing products by a so-called "similarity analysis" [PIC89]. The basic idea is to find existing products which have similar characteristics to those needed in the new design but for which all cost data are available. Those characteristics are also called product cost drivers. Product cost drivers can be the number of parts, quantity or type of material, number of processes, or size among others. Total costs for the existing products are interpolated, or extrapolated if necessary, to obtain an estimate for the expected cost of the new design (see Figure 1-8).

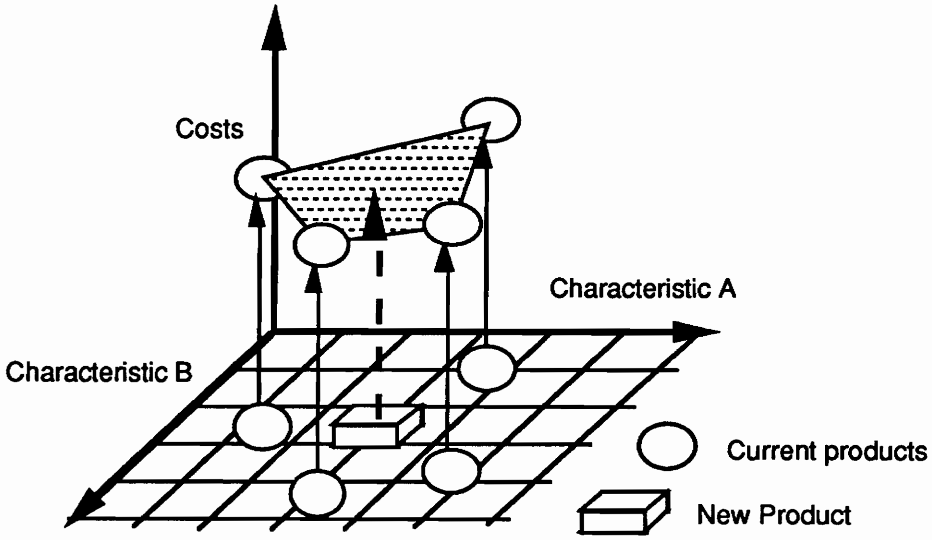


Figure 1-8: Cost estimation using similarity analysis

The problem in performing a similarity analysis for current activity-based systems is that a new design cannot and should not be calculated the same way as the reference products were calculated. In 1923 Clark [CLA23] introduced the principle of "different costs for different purposes." One of these current systems is the CMS-PC activity-based cost management system which was introduced by the CAM-I consortium and which had been analyzed separately prior to this research [WIE90]. Other current systems unable to solve adequately this problem are the approaches described in the Harvard Business School cases (see references).

Consequently, a similarity analysis has to be based on decision costs which frequently differ from the product costs provided by current activity-based systems. Thus, the concept of decision costs is introduced next.

Decision costs

Design-concurrent calculation has to consider costs from a decision perspective. Clark [CLA23] defined relevant costs as "the costs that are incurred if that business is taken and which are not incurred if that business is not taken."

The relevant or decision costs are lower if a company has some unused capacity, which is almost always the case except in a perfectly balanced shop. Products, if designed accordingly, may use that idle capacity, thus making the respective fixed costs of that capacity non-relevant. In consequence, for specific designs capacity costs must not be part of the design decision, making the respective designs more cost-efficient. The point to be made here is that a modern design-concurrent calculation system has to enhance current activity-based systems to account for what degree activity costs are decision-relevant.

The activity consumption of a design alternative is lower when exiting products are re-used as parts or components of a design alternative. (A design alternative to fulfill a stated purpose that includes many re-used parts can be cost-efficient because it can make those of the respective activities non-relevant whose cost drivers are independent of the production quantity). A design-concurrent calculation system must provide the flexibility to consider the "design class" to which a design alternative belongs while also enhancing current activity-based systems by only including certain activities as decision-relevant.

While on one hand most activity-based cost management systems are based on today's costs and activities, the design decision process on the other hand needs future planned costs and activities for good decisions. A design concept which surely is a cost-efficient one today can very well turn into a highly cost-inefficient one in the future. Thus, a good cost management system for design support must be able to provide the flexibility to deal with the activities and their costs in different future time periods by using planning data for its calculations.

Research objective and contribution

The objective of this thesis is to develop a model for developing cost information, regarding design, for decision making purposes.

For any product design alternative presented, the model supports the designer in his/her design selection process with the best possible cost information. This information is available throughout all stages of the design process and it incorporates the anticipated product life cycle, the current company status, as well as the class of the design alternative.

The structure of the model is such that it can be expanded easily by additional modules for other decisions that are based upon the cost management system. Those decisions can, for example, include product abandonment, process investment, non-value adding analysis or similar evaluation questions. This latter model capability is to satisfy the respective core requirement put forth by the CAM-I consortium for research proposals.

The cost model is based on the similarity analysis as a design-concurrent calculation method. The contribution of the cost model can be summarized by the three main features that make it distinct from other models using similarity analysis. All three features deal with a more accurate calculation of the reference products, which is the principal basis of similarity analysis. These features are in particular the calculation according to the dynamic method of investment theory, the use of the activity-based approach, and the determination of relevant costs, as will now be explained in more detail (see also Table 1-1).

1. The product design process is part of the engineering decision making process. In the area of investment theory the engineering economy profession has developed several techniques to analyze similar problems. Existing cost models use what is called a "static method" to calculate the costs of reference products. This means the costs of only one, the current period, are considered in the cost analysis. The cost model in this research uses a "dynamic method" to calculate the costs of the reference products thereby considering the product life cycle costs of the design alternative. Product life cycle costs are the production costs over the entire life span of a product. This way current as well as the future activities and their costs are accounted for. Due to process investments, the activities themselves as well as the cost structure of the company are constantly changing throughout the product's life cycle. Thus, in this thesis investment planning is integrated into design-concurrent calculation as a first step towards concurrent engineering. Also, the economies of scale can be included in the cost analysis because different quantities of the design will be produced in different time periods.

Table 1-1: Distinct features of the cost analysis model

Reference products are calculated ...

#	**Existing models**	**Proposed model**
1	... using current costs in a static method	... using planned costs in a dynamic method
2	... using a volume-based approach	... using an activity-based approach
3	... not for a decision making purpose	... using the decision relevant costs of the design alternative

The second and the third feature accurately determine the data pattern required for the dynamic calculation method.

2. The cost model in this research uses the activity-based cost management approach for the calculation of the reference products because the activity-based approach has proven superior to traditional volume-based approaches. A volume-based approach is used in existing cost analysis models using the similarity analysis method. A discussion of the advantages of the activity-based approach for product calculation was given above. The activity-based approach can be considered as the main characteristic of this cost model. Only this approach can realistically include the concept of a product's life cycle as well as that of the relevant costs only, the third model feature.

3. The third characteristic feature is that the cost model calculates the reference products for the similarity analysis based on the decision costs of the design alternative, i.e., using planned activities as well as relevant costs. Considering planned costs and activities has already been part of the first model feature, the idea of relevant costs is now added. Again, the idea of relevant cost is described by the principle of different costs for different purposes. In general, costs that will appear in the future but were determined in the past are not relevant for a particular decision. Again, the decision costs principle is used because the design-concurrent calculation is part of the decision making process, i.e., it is a problem solving method. The relevant cost concept also constitutes another step towards concurrent engineering in that the company status is considered in the product design process.

Scope and limitations

As ambitious as the objective and contribution stated above are, there are limitations to the research. This thesis shows the conceptual development and a case study of the design concurrent-calculation model. Consequently, the scope of this research is theoretical in its focus. To date, no effort has been expanded to implement the concepts on companies with real costs, activities, and products. No difficulty is foreseen; activity-based cost management systems and design-concurrent calculation cost analysis models based on similarity analysis have been implemented successfully in the past.

In the model the characteristics of the design alternative have to be fed into the cost model before the design-concurrent calculation method performs a cost estimation. The user also has to feed the cost model with current costs and activity information, and current product resource consumption. Furthermore, the analyses require data on planned investments, their cost structure, and their effect on the products resource consumption.

Plan of presentation

Chapter	Description
One:	is an introduction to the conceptual framework of the research. It outlines the similarity analysis, provides some activity-based product cost calculation basics, and specifies objectives as well as scope and limitations of the thesis.

Two: gives a review of the relevant literature. It is divided in the four areas of design-concurrent calculation, the product life cycle costs, the activity-based approach, and the relevant costs which are all four merged in this research.

Three: develops the cost model in its theoretical concepts. First, the general concept of the cost model is presented and from there its detailed concepts are developed. It is examined how costs are traced to activities to obtain accurate activity costs for the past and the future time periods, and it is described what and how information of current products is stored to make it useful for design-concurrent calculation. After having developed the concepts of the cost model databases the design-concurrent calculation method is explained and it is specified how it takes advantage of the stored data.

Four: presents a case study of the cost model. A spreadsheet program and a SAS program were used to implement the cost model. For the case study this model is supplied with fictitious company data. The case study illustrates the structure of the databases as well as the operation of the design-concurrent calculation method.

Five: presents a summary, examines the relevance of this research, and identifies some areas for future research.

Chapter 2

LITERATURE REVIEW

In this chapter the relevant literature is presented which forms the basis of this research. The first section describes where the design-concurrent calculation fits into the design process, and the current cost modeling approaches are described. In the remaining parts of the chapter, the relevant literature is presented upon which the features of the cost model are based. In particular, this will be the product life cycle aspect of costs, further details on the activity-based cost management approach, and the rise of an enhanced activity-based method to determine the relevant costs.

Design-concurrent calculation within the design process

This part of the chapter presents the literature concerning the design process, cost-efficient designing, design to target costs, and existing design-concurrent calculation models.

Patterson [PAT91] states that the design process which includes design-concurrent calculation does not belong to the advanced engineering-analysis processes. He proposes certain characteristics to describe the engineering process maturity level (see Table 2-1). According to Patterson the product development process can only be scaled on a level 2, whereas the manufacturing process has already reached the maturity level 4 in most companies. Level 2 means that the process is repeatable, but also intuitive and very dependent on individuals. This leads to high risk; only a higher process maturity level can ensure productivity and quality.

Table 2-1: Process Maturity Model [PAT91, simplified]

Level	Characteristic	Result
5 OPTIMIZING	Improvements fed back into process	Productivity & Quality
4 MANAGED	(quantitative) Measured process	
3 DEFINED	(qualitative) Process independent of individuals	
2 REPEATABLE	(intuitive) Process dependent on individuals	
1 INITIAL	(ad hoc/chaotic)	Risk

Consequently, the design process is currently characterized by intuition, making it difficult to describe. The German Institute of Engineers (VDI) and the institute setting the German industrial standards (DIN) have presented some guidelines to define better the design process and to move to a higher level. These guidelines including [VDI2222], [VDI2225], [VDI2235], [DIN32992] summarize large portions of research and literature.

The three stage model of the design process

The design methodology provides a three stage model for the design process, which has been accepted by the German Institute of Engineers [VDI 2222]. The design task is to convert functional requirements to part forms. This conversion is performed in several design stages. The design stages are called conceptual design, embodiment design, detail design. During each particular design stage, input information will become more detailed, using the problem solving method explained later in this section. The output of one stage will then be the input of the following stage (see Figure 2-1). During these three design stages the detail level increases as it was shown in chapter 1, Figure 1-7. The following description of the design stages is based on Gröner [GRÖ91].

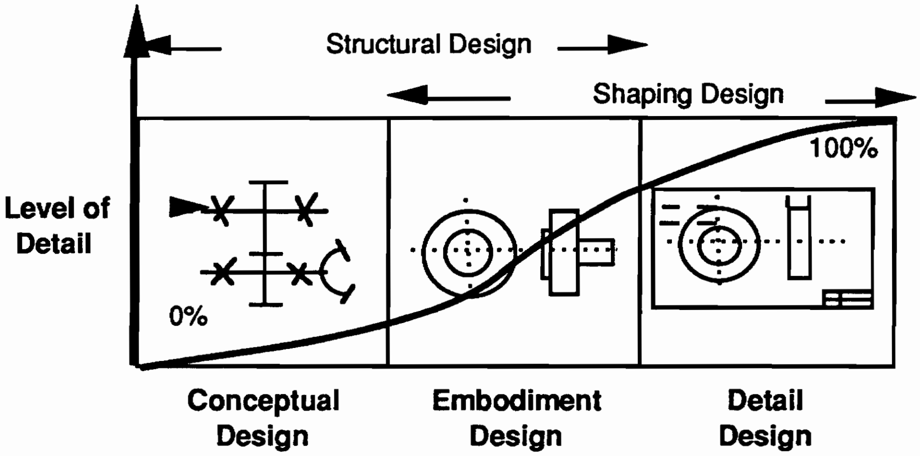


Figure 2-1: The three design stages [BRA88, simplified]

The **conceptual design** stage converts the functional requirements into several functional tasks. Also, the physical and technical effects that could perform those functions are determined. In this stage the designer stays on an abstract level. No actual conversion into forms takes place. The conversion of physical effects into forms is performed during the **embodiment design** stage. The different concepts are captured in sketches and required dimensions are determined. During the last stage, the **detailed design**, the designer makes detailed drawings of the parts. The final form and dimensions as well as manufacturing information are laid down.

Oftentimes there are only two design stages defined. Brachtendorf [BRA88] calls the transaction from function to form the "structural design," and the detailing of the form "shaping design."

The phases within each design stage

According to Ehrlenspiel [EHR89] during each design stage, i.e., at each detail level, the designer uses the traditional problem solving method for proceeding (see Figure 2-2). This problem solving method will be applied more than once at each level. Especially later in the design process it will to be performed for every part (drawing) to find the optimal solutions.

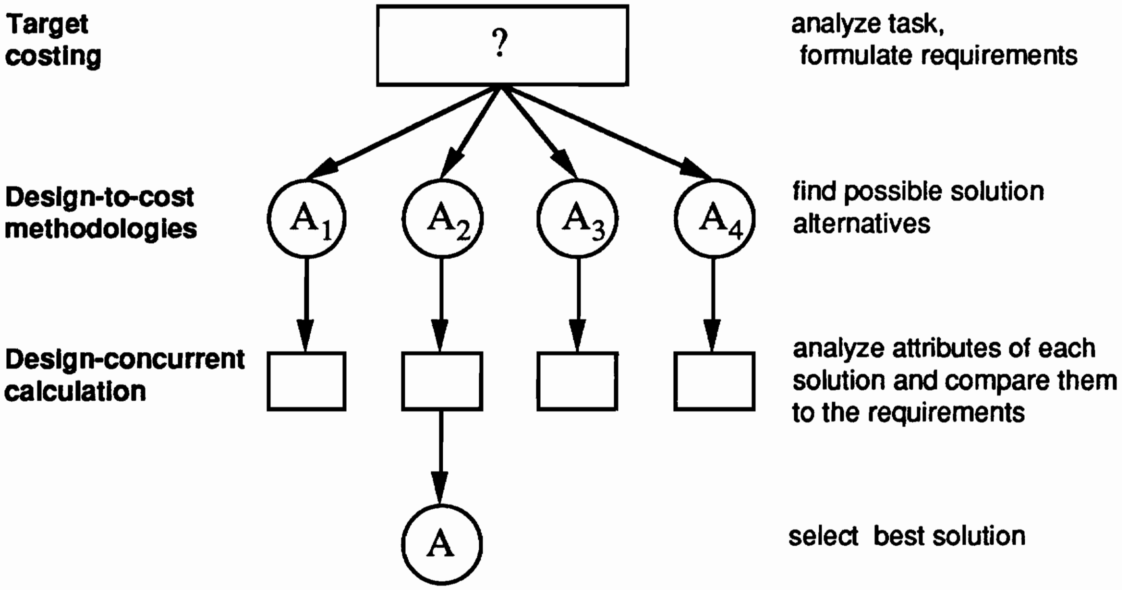


Figure 2-2: Design problem solving method [EHR89, modified]

First, the designer defines the requirements that have to be met during this cycle, including the target costs of the particular problem. Secondly, (s)he has to find possible solution alternatives, this is also called the "synthesis of design alternatives" [EHR89], [SU91b]. In this phase the designer uses several design-to-cost methodologies and guidelines. The design alternatives will either be current products (or their components) or new designs. Thirdly, the designer analyzes the attributes of each solution and compares them to the requirements. In this phase the designer calculates the costs of the alternatives and compares them to the target costs. This calculation is called design-concurrent calculation. Concurrent means that a calculation is performed during the design process while the process plan or bill of activities has not yet been determined [EHR85]. A cost-efficient design can be accomplished by using a design-to-cost methodology iteratively in combination with design-concurrent calculation [ULR90].

Phase 1: Target costing

In the first phase the functional requirements as well as the target costs are determined. The formulation of the functional requirements often follows an approach called "quality function deployment (QFD)," which is a participative approach that translates costumer wants and needs into specific product characteristics [SU91b]. Participative means that design and marketing departments closely work together.

Michaels [MIC89] defines a target cost goal as "a specific number ... based on a specific production quantity and rate, established early during system development as a management objective and design parameter..." For every product a target cost can be found when it is compared to the desired market value. VDI 2225 recommends to set the target cost of production at around 70% of the achievable market price.

Designing with a target cost is used more and more [SU91b], especially in Japan [SEI91]. A product that seems to be designed perfectly, meeting all the functional requirements and being designed the most cost-efficient way for a particular company, will still not succeed in the market when the production cost are too high and, thus, it cannot meet the market's price expectations [GRÖ91]. For this reason the design-concurrent calculation has gained its recent popularity. Design-to-cost methodologies only are not sufficient in today's competitive environment.

Sullivan [SU91b] points out that by using design-concurrent calculation the designer can determine continuously during the design process how likely it is to reach the cost goal. The costs can be reduced when designers and engineers consider some trade-offs through design-to-cost methodologies or, again, agree with marketing on changes in the functional requirements. It might even be necessary to drop the project after it has completed the design stage.

Phase 2: Finding solution alternatives by design-to-cost methodologies

VDI 2235 outlines which design-to-cost methodology should be used in each particular design stage (see Table 2-2). The design-to-cost methodologies will not be part of the cost model and are subsequently only summarized to give a complete picture. It is up to the designer to find cost-efficient design alternatives. The cost model will then be used in the next step to estimate the costs of each alternative presented. The model can support cost-efficient designing by changing certain parameters of the design and then re-calculating the modified alternative again.

Table 2-2: Recommended design-to-cost methodologies at different design stages [VDI 2235, simplified]

Design stage	**Design-to-cost methodology**
Conceptual design	ABC analysis relative (function) costs global design rules
Embodiment design	relative costs good/bad examples participative methods
Detailed design	-

ABC-Analysis

For target cost designing, a maximum error tolerance for the total costs is specified and each part subsequently receives an individual error tolerance. Due to error summations, errors will partly balance one another, so that individual errors are not as tight as the global tolerances [SCH91], [EHR85] (see Figure 2-3). A-parts will have

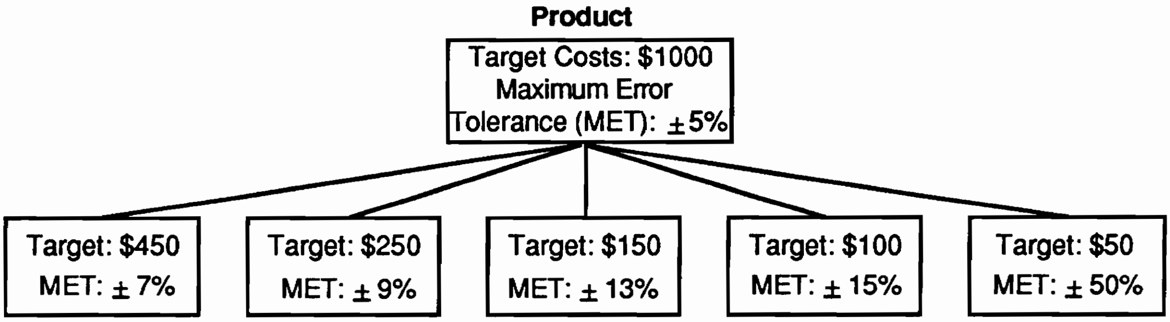


Figure 2-3: ABC-analysis of target costs [SCH91]

the smallest tolerance and consequently VDI 2225 recommends to design them first at every stage. In case the tolerances cannot be met corrective actions can then be taken early in the design process.

Relative cost catalogs

Since the late 1960's research interest in Europe has shifted towards relative cost catalogs as a design-to-cost method. Relative cost catalogs are external guidelines that provide the costs for an object in proportion to a reference product. However, they do not offer a specific cost amount as this will vary among companies. Relative cost catalogs exist for different product functions [VDI 2222], possibilities to join parts [DIN 32992], various surface qualities and other characteristics. Ehrlenspiel has done research with Fischer (gears) and Hafner (welded and casted parts) to come up with different external catalogs on relative cost for products and components [EHR85]. "The main advantage of relative costs is that they can provide a fast and easy way to find the cheapest alternative in a collection of possible solutions" [WIR90]. The main disadvantage is that those factors are external guidelines and that actual cost can be very company dependent" [WIR90]. Relative cost catalogs are not only classified as a design-to-cost but also as a design-concurrent calculation method [EHR85], [VDI 2225].

Global design rules

Many global design rules can be found in the literature [EHR85]. One example is to "reduce the number of parts required where possible by designing one part so that it performs several functions" or "design to use general purpose tooling rather than a special one" [WIR90].

Good/Bad guides

Good/Bad guides or rules are frequently presented by graphical examples of good and bad construction methods. Many examples can be found in [EHR85], [BRA88] and [VDI 2225]. They represent a large part of the experience gained in previous designs and manufacturing, assembly processes and are often not limited to external guides [EHR89].

Participative approaches

The two main participative approaches are called "design for assembly (DFA)" and "design for manufacturability (DFM)" [SU91b]. DFA represents an approach to design-to-costs by reducing the number of parts in a product and by improving the way those parts are to be assembled. DFM seeks to improve the manufacturing characteristics of a product [BOO88]. Participative approaches mean that there is an active link between design and manufacturing/ assembly departments.

Support systems

Design support systems are not mentioned in Table 2-2 by VDI 2235, however, they belong to the design-to-cost methodologies. The concept proposed by Brachtendorf [BRA88] received significant attention as an information system approach for DFM. Bässler [BÄS87] developed an information system concept for DFA, which has been a benchmark in this area. Scheer, a major researcher in the CIM environment, presents a concept of an expert system for universal design support [SCE90]. The objective is that the system support leads to a design that considers the requirements and the abilities of the major business functions which follow this design process.

Phase 3: Analyzing the different alternatives using design-concurrent calculation

Methods that estimate the production costs during the design stages are called in the technical literature design-concurrent calculation methods. There is one participative method called "value engineering (VE)" and there are several cost modeling methods.

Value engineering (VE) is a participative approach that involves several departments by including members from marketing, design, process planning, and calculation among others. It focuses on relating cost values to design functionality. The cost estimation of this organizational or management methodology is based on expert knowledge [FRA90].

While the participative approach does not play a role in this research, the cost modeling methods do. The following three cost modeling methods are distinguished: the analogy method, the search method, and the similarity analysis. The analogy method determines the required activities as well as their costs from the known design characteristics. The other two methods, the search method and the similarity analysis, use the known characteristics to select current similar products for which the costs are known and then analyze their cost structures.

Analogy method

In the analogy method all the required activities of the product life cycle are simulated and the costs of each activity are allocated to the product. This method generates a bill of activities from the known characteristics of the design alternative (see Figure 2-4). Ulrich and Fine [ULR90] proposed a cost model to estimate the cost of printed wiring boards using the analogy method. "First the designer specifies the attributes (characteristics) of the board. Next our system must determine the process plan by specifying the process steps necessary to realize the specified board attributes. Third, the yields at each of the process steps are computed based on the board attributes and relationships derived from models from physical process and historical data (activity usage function). Based on the resulting yields and other information, like set-up times, the manufacturing resource requirements and batch sizes are determined. Once resource requirements, process steps, and process yields have been estimated, the costs at each process step can be computed. Finally these costs are displayed to the user. The user can interactively make modifications to the board design to reduce production costs." The proposed "model will use the activity-based accounting scheme in which overhead costs are computed at each process step" [ULR90].

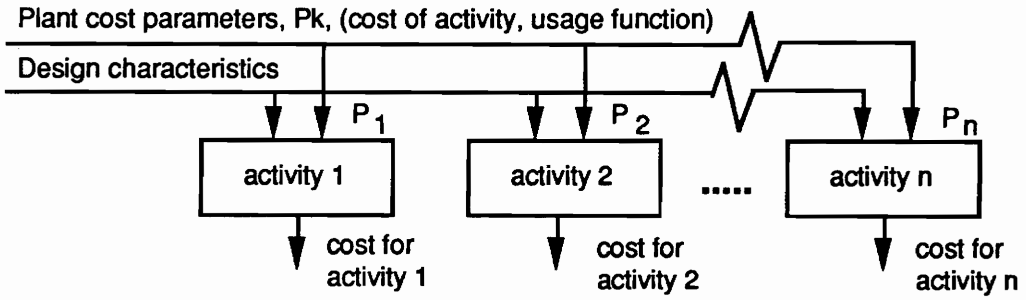


Figure 2-4: Product cost calculation of a design alternative using the analogy method [ULR90, modified]

The analogy method which does consider activities is valid only later in the design process when more details of the design are known. The analogy method tends to be more of an activity planning tool with cost calculation capabilities rather than a design-concurrent calculation method.

Search method

In the search method the costs of the product which is most similar to the design alternative are assumed to be the cost of that design alternative. One of the main studies about the validity of this method was performed by Hillebrand [HIL86]. In order to determine the similar products to the design alternative, a more-dimensional cost influencing factor table, also called characteristics table, is developed. All current products are placed in the table along with the design alternative. Similarity is reflected by the distance in the table [HIL86].

One example of how product characteristics can be determined is Pickel's [PIC89] analysis of the factors influencing total costs of cast paddle wheels. Only for the process casting, he found 45 cost determining factors, which were geometrically dependent and material specific characteristics. By using statistical analysis he was able to reduce those 45 factors to seven main characteristics, each having a strong correlation with costs. There has been extensive research trying to determine the main characteristics for different products, components and parts [PAH82], [WIT84], [EHR85], [HIL86]. It has been shown that product families can be defined such that products of the same family have the same main characteristics, while the characteristics differ for products from different product families. To determine the main characteristics is very difficult and is usually done through extensive regression analyses from all cost driving characteristics [PIC89].

Product families on lower levels of detail have cost driving characteristics that are more concept related, such as horsepower for machine related part families, while part families on higher levels of detail have more form specific characteristics such as surface quality and tolerances. Every component or part will belong to only one particular product family (see Figure 2-5).

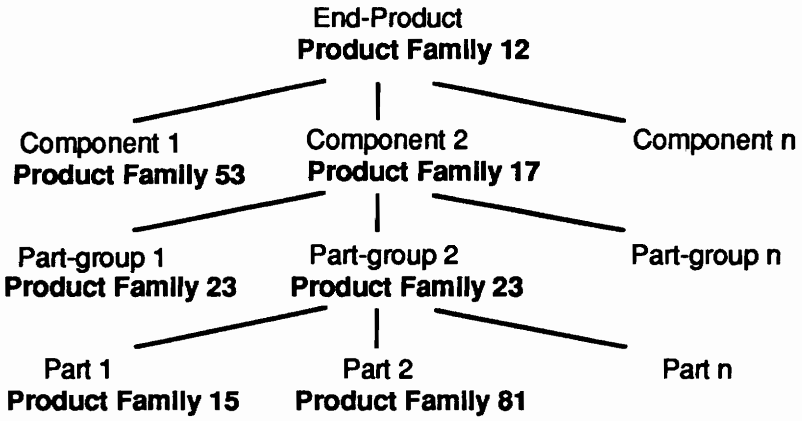


Figure 2-5: Each product element belongs to one product family

The concept of building product families was initiated by Opitz [OPI63] in his benchmark survey which was eventually standardized in DIN 4000. He grouped the product families on very different criteria; including process and material characteristics rather than cost driving characteristics.

The search method was not the methodology of choice although it uses cost information for a reference product. The problem with this method, however, is that it cannot give any cost estimation for improved different designs for which no similar products exist.

Similarity analysis

Similarity analysis uses several similar products as reference products and analyzes their characteristics with the help of statistical methods. It requires statistical methods of analysis such as regression, to consider several products and several characteristics. The analysis generates a function of these characteristics and the cost of the design can be estimated from this function. In general, when the cost influence of some main characteristics is understood, then a calculation of a design alternative is possible based upon those characteristics (see Figure 2-6).

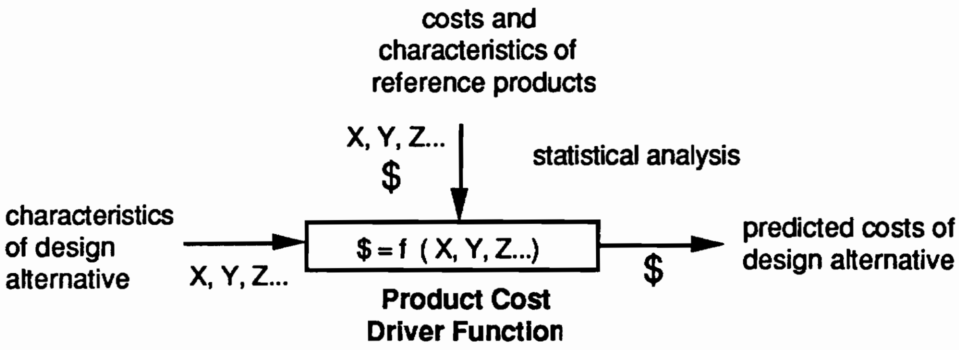


Figure 2-6: Cost estimation of a design alternative using similarity analysis

Sometimes in what can be considered a simplified version of similarity analysis the calculations are based upon only one characteristic and the cost of one known reference product. The assumption is always that one influencing factor rises in the same proportion to the production costs. DIN 32990 states that these methods are most of the time used for design changes of similar geometric products, like for variants that differ in size. Two well known approaches are weight-based methods and size-based methods [GRÖ91]. The following equations are taken from DIN 32990:

$$\beta = Y_r / X_r \quad (1)$$

$$Y_d = \beta X_d \quad (2)$$

Y_r = Costs of reference product
X_r = Amount of characteristic of the reference product
Y_d = Estimated costs of the design alternative
X_d= Amount of characteristic of the design alternative
β = Coefficient

This method suffers in that the cost influence can oftentimes not be described by only one characteristic. For example, when the material costs are used as as the basis, the quantity effect is not considered. The problem is similar to the one faced by the traditional volume-based calculation methods described in chapter 1.

The regression analysis can be performed on several characteristics of similar products with the product characteristics being the independent variables and the total costs being the dependent variable [EHR85]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_N X_N \qquad (3)$$

Y = Costs
X_i = Amount of characteristic i $\quad i = 1,2,\ldots,N$
β_i = Coefficient i (values determined by ordinary least squares regression)

Because independent variables in the regression are oftentimes correlated, a negative coefficient can be determined by fitting a least squares straight line. Thus, the designer cannot conclude from these coefficients which of the characteristics have the greatest impact on total costs. The designer can only include all the characteristics of a design alternative into the equation to receive a cost estimation.

Schaal [SCH91] built the KIS cost information system using similarity analysis. It is a CAD-based system that can calculate design features. In a first step feature-based information is extracted from the solid-model CAD-system and transferred into the cost analysis model. Then, a search module retrieves similar, known features from current products and finally the model performs the similarity analysis. The resultant cost information is limited to the manufacturing costs which are the costs of all the processes listed in the traditional process plan.

Pickel [PIC90] developed the GUSSKAL cost information system for cast steel parts which is also based on the similarity analysis. The design characteristics description is supported by an expert system that can derive missing characteristics by knowing others. Calculation results include the material costs, the die construction, the casting operation, as well as metal removal operations on the casting. The reference products are calculated using the traditional volume-based overhead allocation method. The program is used successfully in industry to calculate bids. The weight-based estimation technique showed a mean error of 27% whereas the GUSSKAL only has a mean error of 4% when comparing the estimate to the calculation done after the order had been completed.

The similarity method provides the best approach to estimate accurately especially new designs as the cost influence of characteristics is analyzed. Therefore, the similarity analysis provides the basis for the cost model developed in this thesis. A CAD-based interface was not added to this structure because it uses features which would have limited the model for later design stages. Features are limiting for the reason that they describe even a higher detail level than that of the parts.

Life cycle costs

It is important to specify what costs have to be calculated in the design-concurrent calculation phase. The literature differentiates two different types of costs relating to the products' life cycle: Total product costs and production costs. On the other hand any product can be considered as being a project or an investment. For projects the literature proposes two different ways for their cost calculation, the static and the dynamic approach. It will be shown how and why the cost model approach differs from existing cost analysis models in its way of considering a product's life cycle.

Total product costs vs. production costs

When following the idea of total product costs, life cycle costs are understood as the total of all costs that will be incurred by the product's end-user. They can be divided into once-only costs and continuous costs [VDI2235]. Once-only costs not only occur in the purchase of the product, but they also include costs for training and instruction as well as costs for product destruction and disposal. On the other hand, continuous costs include those for energy consumption, wages for the operator and costs for repair and maintenance. The designer has considerable influence on all kinds of costs [EHR85]. It should be his goal to minimize these total costs, because the consumer will evaluate all costs in his investment decision. This idea of product life cycle costs, however, does not receive any further attention in existing models based on similarity analysis, and it will also not be considered in this research.

The focus of this thesis is on those costs only that are incurred by the producer. In this second approach towards life cycle costs, only production costs are considered. They include all the costs a product is responsible for during its production. Production costs are the costs from all those activities that are included in the bill of activities and all the costs of the materials that are included in the bill of materials. The sum of these costs plus the company's profit form the market price which then constitutes the biggest portion of the customers' once-only costs described above. These production costs are called the target costs in VDI 2235 and VDI 2225 and are estimated by other existing design-concurrent cost analysis models as well as by the cost model of this research.

Static vs. dynamic calculation method

The following comparison between the static and dynamic calculation method is based on Bullinger [BUL90] (see also Table 2-3). The literature in engineering economy uses a similar distinction and arguments [DEG88], [THU89].

Table 2-3: Characteristics of the static and dynamic calculation method [BUL90, simplified]

Static method	**Dynamic method**
Costs taken into account over one service period only	Costs taken into account over all service periods
Limited to average values of costs	Fluctuations of costs can be considered
Interest on costs ignored	Interest on costs of subsequent service periods considered
Small data base	Large data base

For the sake of simplicity, the static method of economy calculation is based on assumptions which are themselves not borne out in practice:

- Costs are equal in all periods during the service life
- Interest on costs are not taken into account

The static calculation method is very simple and as a consequence cannot produce very precise results. It is frequently used in practice, especially where

- an economy calculation is to be performed simply and rapidly
- a decision is to be taken of minor importance

The relatively small calculation expenditure involved and the low quantity of data required, usually for one period only, can be named as advantages over the dynamic method. These very advantages also result in the problems of the static method, as the latter mainly provides only rough reference points regarding the basic question of economy calculation.

Contrary to the static method, it is the characteristic for the dynamic method not to work with average values but to consider the differences in the accrual costs. Also, it uses compond interest. The higher expenditures incurred by the use of the dynamic method make it expedient to use in the case of particular important investment decisions.

Existing design-concurrent calculation cost models use the static approach the basis for their cost estimation, i.e., the reference products are calculated using the static method. Thereby, they only consider one time period, usually the one containing current costs. Minimizing the **current** production costs is not necessarily the same as finding the most cost efficient design because

- activities themselves change over time and their costs also change.
- the production quantity of the design will be different in different time periods of the product's life cycle.
- pre-production and production time periods have very different cost structures.

A more comprehensive approach is to consider the production costs throughout the product's entire life cycle. The product life cycle is the time period during which the product is part of the company's production program. Berliner and Brimson [BER88], and Noble and Tanchoco [NOB90] among others as well as the CAM-I consortium

[PRY88] recommend to base all design-related decisions on this product life cycle approach. As a result it is necessary to estimate the production costs for each time period of a product's life cycle separately [NOB90] (see Figure 2-7). This is the approach the cost model in this thesis is taking.

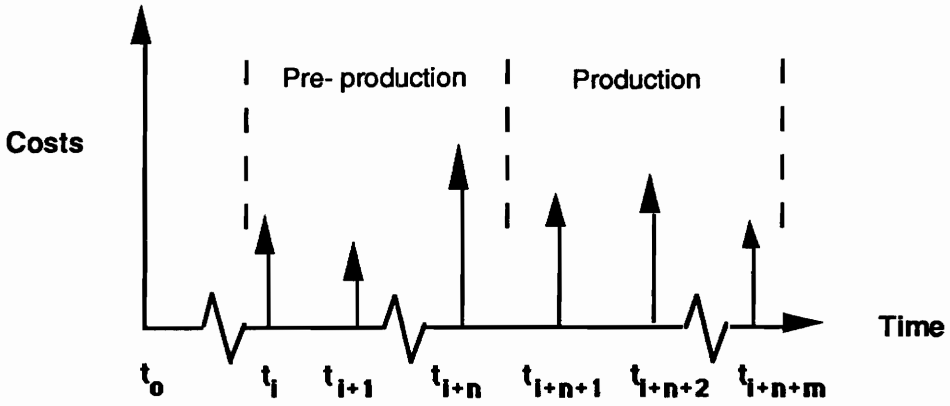


Figure 2-7: Product life cycle costs [NOB90, modified]

Activity-based Cost Management

In this section the approach taken in the literature towards activity-based cost management is reviewed. This review shows that the activity-based approach is not a new one but rather a revision of the traditional engineering practice, which has become more and more necessary due to the changing paradigm in the manufacturing environment. Then, the activity-based approach is detailed and different approaches towards activity costing are shown. Finally, computer-based applications and current company implementations are reviewed.

The re-invention of the activity-based method

In the beginning of the 20th century, the company's operations and their decision making was primarily influenced by engineering viewpoints. The problem area of concern within a company was the optimal control of the operating manufacturing activities. The cost management system followed the same objective [EBE90]. This phase was influenced primarily by the Scientific Management movement of the engineers F.W.Taylor and F.Gilbreth.

However, in the late 1920's, along with the introduction of capital markets and external auditors, there was a need to introduce financial accounting techniques to present information about the company's financial situation [BOR90]. All data had financial character and used the volume-based method described in chapter 1. "The auditors' method of valuating inventory ... provided a lower cost alternative to costing products ... than techniques proposed by the scientific management approaches. The requirements of such statements gave financial accounting a higher preference" [JO87a].

In 1936 Dean [DEA36] indicated the notion of cost variability different from product volume, which is similar to the activity-based approach: "Since total cost is a function of many variables, cost may be regarded as marginal with each of these variables. Increasing the number of new styles, for example, has a marginal cost analogous to that resulting from increasing number of units of output."

"In the 1950's ... businesses began to use financial accounting information to direct management decisions ... : to control workers and subunits ... planning the extent and financing of the enterprise ... Historians now believe, that financial ... accounting information intruded upon and distorted the financial and other information companies had used for decades to manage not only operating activities ... but also strategic product choices..." [JOH91].

Many believe that using financial accounting information to plan and control business activities contributed to declining competitiveness and profitability in many American manufacturing companies starting in the 1970's. Due to the changing manufacturing environment "a much higher percentage of employees were used to support the production process.., but the cost system continued to stress direct labor efficiencies, and measure product costs based on their direct labor content" [KA91b]. Sullivan [SU91a] characterizes the changing manufacturing environment by outlining its changes (see Table 2-4).

Table 2-4: The advanced manufacturing environment [SU91a, simplified]

Yesterday	**New Paradigm**
High volume, long production runs, long product life cycles	Low volume, short production runs, short product life cycles
Small number of product variations in a domestic market	Large number of product variations in a domestic market
Large direct labor component; high cost of processing information	Relatively high technology costs; relatively low information processing costs
Small indirect/overhead costs in relation to direct labor	Large indirect/overhead costs in relation to direct labor

Pryor [PRY88] explains what is meant by only managing the company based on volume-based financial systems. "Cost management is not focused to where the cost are" (see Figure 2-8).

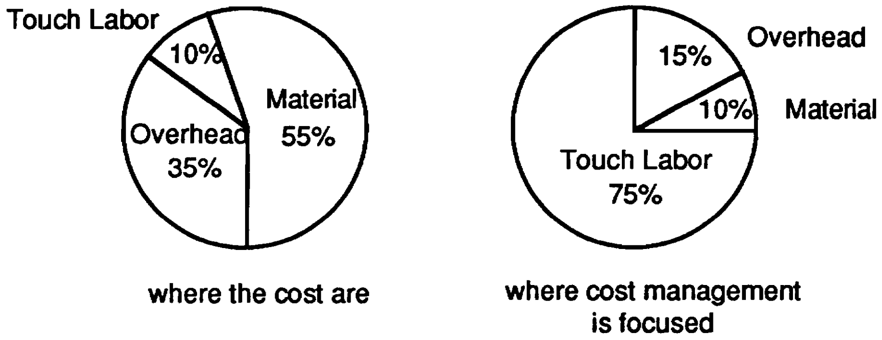


Figure 2-8: Cost management has not addressed the new manufacturing environment [PRY88]

Actually, it is the field of engineering economy that "deals with the concepts and techniques of analysis useful in evaluating the worth of systems, products, and services in relation to their costs" [THU89]. It is the engineering economy profession that used the financial cost data for their evaluations and thereby failed to take action against this increasing distortion of cost information. Horowitz [HOZ76] is the first to criticize this, also pointing out that "Engineering economy has, to all intents and purposes, been at a virtual standstill for the past quarter of a century."

Sullivan [SU91a] emphasizes that the early call from Horowitz has finally found response and that a paradigm shift has lately taken place in engineering economy by the introduction of, for example, the activity-based approach. Now, there is an "increasing emphasis on producing accurate and timely information, for decision making, that is devorced from a firm's financial accounting (external reporting) requirements" [SU91a]. This change in paradigm away from traditional cost management took place in the middle of the 1980's, initiated mainly by accountants. There were many publications that showed the limitations of management accounting practices for most kinds of engineering decisions [CO88a], [CO88b], [KAP84], [JO87b]. They all emphasize that accounting systems and their data are designed for financial reporting and not for the engineering decision making what they are used for.

Details of the activity-based approach

The CAM-I CMS consortium [PRY88], Miller and Vollmann [MIL85] and Dilts and Russel [DIL85] among others initiated the philosophy for a better reporting and managing of costs using an activity-based approach. The "relevance lost" [KAP84] had been changed to "relevance found" (according to Len Moore, the program manager of CAM-I CMS) [FRÖ91]. "If as we believe, transactions are responsible for most overhead costs in the hidden factory, then the key to managing the overhead is to control the transactions that drive them" [MIL85]. This approach goes back to pre-war engineering practices which primarily looked at the required activities. For Brimson [BRI91] only those processes qualify as activities where the preposition "to" can be added to emphasize that something is processed there, e.g., to operate drilling, to move material, to place a purchase order etc. The activity-based approach was publicized mainly by Cooper [CO88b], Johnson [JOH88], Kaplan [KAP88], [KA89c], [KA90a], Turney [TUR89], [TUR91], and Brimson and Berliner [BRI86], [BER88]. The basics of this philosophy were explained in chapter 1. Additional details are reviewed next.

Consolidation of activities

Horvath [HOR90] and Brimson [BRI91] consolidate activities to "main activities" [HOR90] or "major cost drivers" [BRI91]. A main activity accumulates activities of different business functions. This way the cost impact of a certain cost driving activity, e.g. "to introduce a new product" can better be examined [HOR90]. In Horvath's example the main activity "to introduce a new product" includes to develop a process plan, to program the NC-machine, to develop a plan for quality control, to maintain the process plan, and to adjust the production program. Therefore, the activity "to introduce a new product" requires activities from several business functions (see Figure 2-9).

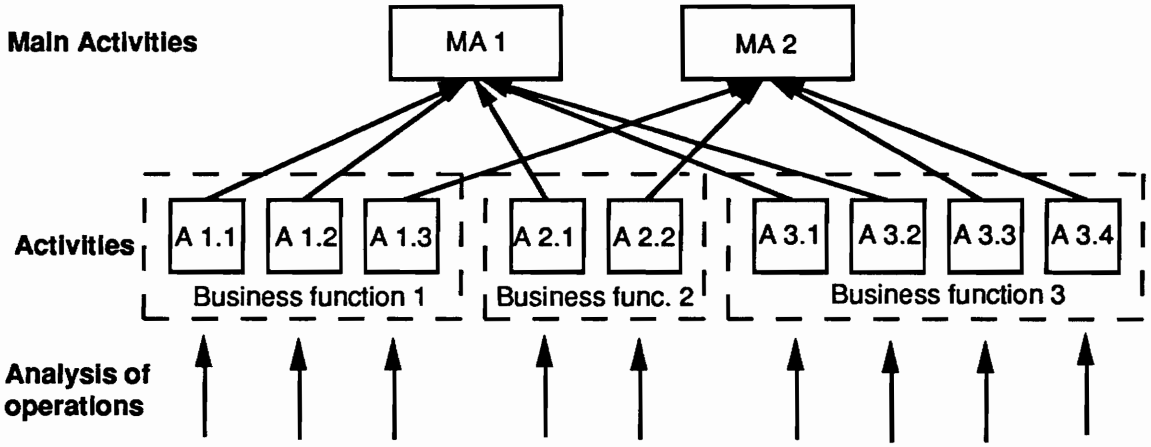


Figure 2-9: The consolidation of activities to main activities [HOR90]

The consolidation of activities to main activities or main cost drivers will not play a role in the cost model and is only mentioned to provide a more complete picture of the activity-based approach. For the reference products all required single activities can be observed during production and are stored in the bill of activities. In this case a consolidation of activities is not required for calculating the costs of those products.

Activity cost driver costing

In the activity-based approach for every activity a cost driver is determined which best reflects the cost influencing factor of the respective activity. In order to determine the cost for each cost driver, the CMS-PC system divides the traced costs by the amount of cost drivers performed within a certain time period [WIE90]. Kaplan comments on this procedure as follows: "Many companies make the mistake of taking their total spending on resources and dividing it by actual output" [KA89a]. Riebel [RIE85] is explaining that by so doing idle capacity costs are distributed over their usage (see Figure 2-10). Kaplan [KA91a] points out that activities with a lot of spare capacity will then be more expensive that others. "At first we thought that the cost of excess capacity was a side issue to ABC but one now realizes that excess capacity costing is not a side issue - it's a central issue" [KA91a].

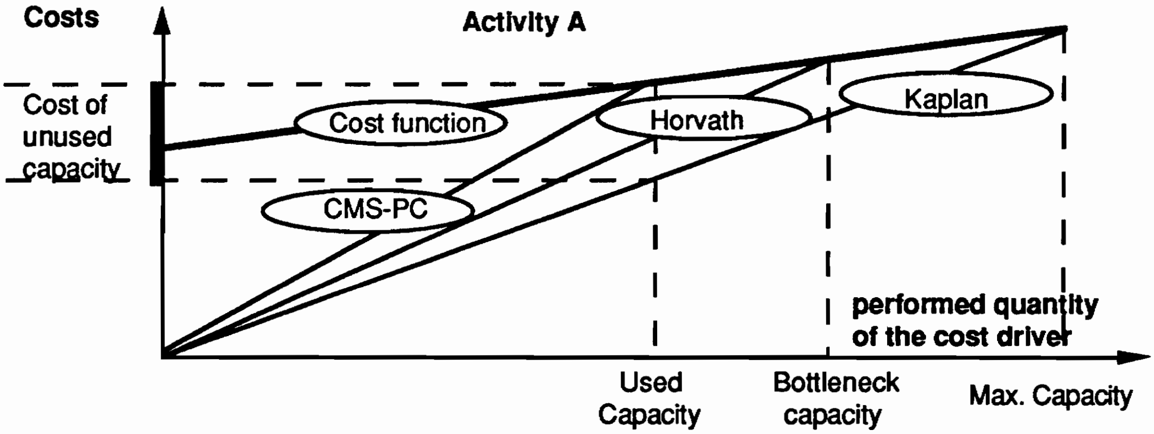


Figure 2-10: Different costs for an activity cost driver; also the costs for unused capacity made visible.

In order to solve this problem and to make activity costing accurate, Horvath [HOR90] recommends taking the capacity of the company's bottleneck activity as the reference for all other activities. Glaser [GLA91] criticizes this procedure for being not practical. Kaplan considers the maximum capacity of every activity as reference [KA91a], for two reasons: Firstly, he advocates a long run perspective for cost management according to the principle "spending will follow usage," thus, in the long run there will be no idle capacity. Secondly, this approach will make the cost of the current idle capacity visible [KA91a]. The correct activity costing, i.e., finding the accurate cost per activity cost driver, will play an important role in the cost model.

Computer systems

One area that has not received much attention is the interface between activity-based cost management and computer systems. It was mentioned above that the CAM-I CMS consortium has presented a system [WIE90] which will be used as a reference in this research. In addition, the consulting company Peat Marwick developed together with Cooper and Kaplan the system "REVEAL" which is similar to CMS-PC according to a study by Fröhlich [FRÖ91]. The main difference is that it also determines main cost-drivers (main activities), as Brimson and Horvath had proposed for the activity-based approach.

Custom-made applications

Tektronics designed an activity-based approach to achieve cost-efficient product designs. Tektronics introduced a continuous improvement program consisting of just-in-time (JIT) production and total quality control (TQC). By reducing the content of labor, the old labor-based cost accounting system lost even more of its accuracy. Tektronics introduced an activity-based approach selecting the "number of part numbers" as the cost driver for allocating overhead costs to products. By using part numbers as a cost driver, designers realized that low-volume parts and a large number of parts in a product drive the costs. This approach is also called material burdening. "We design products differently under material burdening from the way we did with the old system where all overhead was charged to labor. With material burdening, we now recognize the acquisition costs plus the carrying costs of components. This knowledge.... guides the (design) process to the minimum true cost of doing business, not just the lowest parts costs."

John Deere's activity-based cost management system is designed for better product calculation. John Deere's traditional cost system used the three cost allocation bases of labor, material cost, and machine hours. They were losing business for high-volume orders and gained business in low-volume orders. Having recognized this problem they moved into an activity-based approach by retaining labor hours, machine hours, and material dollars as unit level driving allocation bases, adding three batch level drivers (setup hours, production orders, and material movements) and by also adding a product sustaining cost driver (keeping a part in the system). The new system gave managers a better insight into the nature of their expenses when deciding on whether or not to accept new orders. Furthermore, it also influenced the design decisions with respect to the number of different parts.

Cost Management providing decision costs

Volume-based relevant costing approach

The "direct costing," as a first relevant costing approach, can be traced back to Harris in 1936 [SIN85]. Kaplan explains the direct costing approach as follows: "One cost pool - the fixed expenses - includes those expenses that do not change with respect to short run changes in production levels; the other pool includes those expenses expected to vary with short-run changes in production volumes. In the so-called direct costing approach, the fixed expenses ... are left unassigned. They are ... not considered relevant for product decisions ... It is the foundation of what is taught about flexible budgeting ... and decisions on accepting incremental orders or make-versus-buy [KA89b]."

Männel [MÄN82] among others [AHL88], believes that fixed costs are actually defined mistakenly. Capacity costs are often called fixed costs and operating costs are called variable costs, although they are very different types of costs. The capacity costs are time-related, whereas the operating costs are output-related. This means that only in the short-term capacity costs can be considered "fixed," as done in the direct costing approach. However, for the long-term capacity costs must be considered as variable costs [FRÖ91]. Riebel [RIE85] calls this the "principle of relativity."

Under these circumstances it must be determined which costs are actually relevant for a certain decision, i.e., which costs can be traced to a particular decision [KIL84]. In

1923 Clark called this method "different costs for different purposes," whereas Riebel [RIE85] calls it the "principle of identity."

The activity-based approach providing decision costs

Currently, in the U.S. the activity-based approach is not decision-oriented. All costs are traced to activities so that it is not visible to a manager what portion of the total costs reflects fixed and what portion reflects variable cost. This procedure was chosen because of the bad experience with the direct costing approach [FRÖ91]. The companies "do not worry about fixed costs because they do not change with the decision ... In fact, if you look over the last two or three decades, the costs that have increased the most within organizations have been those that management accountants have called fixed. It strikes us as peculiar that the costs that have varied (increased) the most are the costs that have been classified as fixed" [KA89b]. However, in 1991 Kaplan [KA91a] admits that the activity-based approach needs to re-focus. The first step is to make idle capacity visible (see the fourth section of this chapter).

Reichmann [REI90] realizes that in the existing activity-based approach too much information is still hidden and in 1990 introduces a cost management system called "a fixed-cost-management oriented plan-cost system." This approach has lead to considerable attention in the field of cost management in Germany [FRÖ91]. It is an activity-based approach which also records planned cost data and differentiates capacity costs and operating costs. The capacity costs include information about the time period for which they are "fixed," and also information about idle capacity that is available. This "fixed-cost-management oriented plan-cost approach" can be considered a starting point from which the cost model with its three distinct features evolved that form the research contribution of this thesis.

Chapter 3

CONCEPTUAL DEVELOPMENT OF THE COST MODEL

The literature review in chapter 2 has confirmed that the costs of a design alternative can be predicted accurately when basing the prediction on the cost of existing products with similar characteristics, i.e., products from the same product family. This conclusion provides the starting point of this research. The cost model presented in this thesis estimates the cost of design alternatives based on similarity analysis. In order to determine the cost influence of the relevant characteristics or, in other words, to pinpoint the relevant product cost drivers, similar existing products must be analyzed carefully. The cost model provides the means for an accurate cost estimation of the reference products.

General concept of the cost model

Many activity-based cost management systems are used as a second cost management system in addition to the accounting system which is designed to satisfy tax regulations. This is how Kaplan [KAP88] initially introduced activity-based cost management, as a parallel system, but he also realized that these systems are getting so complicated that not many U.S. companies are willing to introduce them additionally. Now, as a result, Kaplan promotes a one-system approach to support management decisions as well as to fulfill tax requirements [KA90a]. The cost model presented in this thesis is such a one-system approach. The system is available for periodic financial accounting requirements as well as for case specific decisions, one of them being the design-concurrent calculation.

The cost model is operating according to a two step principle. In the first step costs and other relevant data are collected and recorded in a neutral way. "Neutral storage" means that no information is lost through any kind of proportionalization of data, which would make different data analyses impossible, or biased to say the least. In the second step this datapool is then available for periodic financial accounting requirements as well as for case specific decisions.

The cost model uses two main databases: the activity costing database and the product information database. The activity costing database ensures accurate activity cost information by storing the company's activities, the activity cost drivers, the observed and planned cost driver quantities, and the traced costs. The product information database records information about the current products. This includes for every product the product structure, the production plan, the main cost driving characteristics, the bill of activities, and the cost of materials. No activity cost information is stored in this database. Both databases store historic data from the past as well as planned data for several future time periods. In both databases a separate file is kept for every time period (see Figure 3-1).

So-called "methods" perform calculations for the various evaluation cases. A method is a program that specifies the search conditions for a particular problem and performs the arithmetic on the retrieved data. This thesis focuses on the method of the design-concurrent calculation.

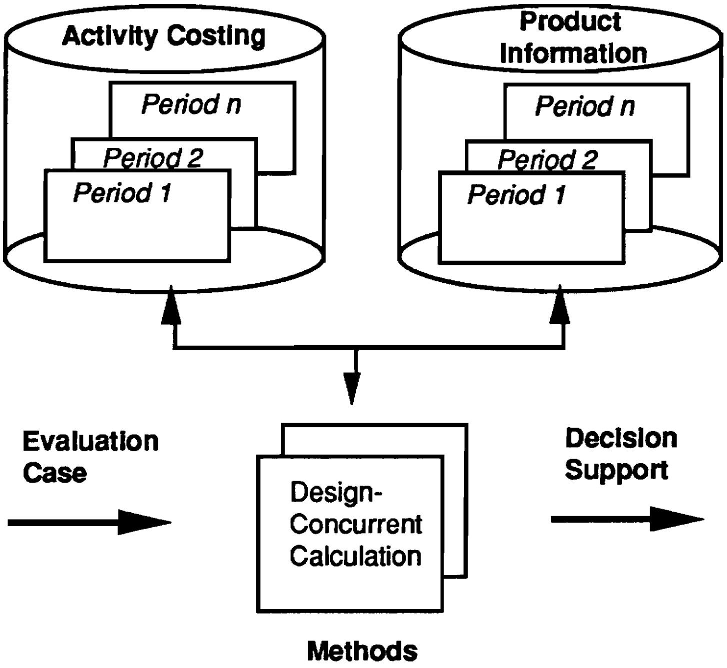


Figure 3-1: General concept of the cost model

The contribution of the cost model lies in the way the reference products are calculated for the similarity analysis. In particular, the design-concurrent calculation method calculates the reference products as if they were the design alternative, i.e., it calculates them based on the decision costs of the design alternative. This leads to improved cost information for decision making regarding product design. The concept of the design-concurrent calculation method is briefly explained next, and will be discussed in detail in the last section of this chapter (see also Figure 3-2).

The designer has to specify first the characteristics of the design alternative. Based on this information the design-concurrent calculation method searches for those products that have the same type of characteristics, because only products belonging to the same product family qualify as reference products for the similarity analysis.

The design alternative is to be evaluated for possible implementation in the future. Current costs as well as activities and materials from the current bill of activities of the reference products should not be taken directly as a reference. Over time the activities change due to process investments. Similarly, the costs of activities and the costs of materials are changing. Thus, in the cost model of this thesis the reference products are separately calculated for every time period in which the design would be produced. The reference products are calculated using the bill of activities that will be estimated for a specific time period, i.e., the bill of activities is likely to be different in every time period due to changing activities.

Furthermore, only the relevant costs of a design alternative are considered for the calculation of the reference products. Not all activities that appear in the bill of activities of the reference products, and not all activity costs listed in the activity

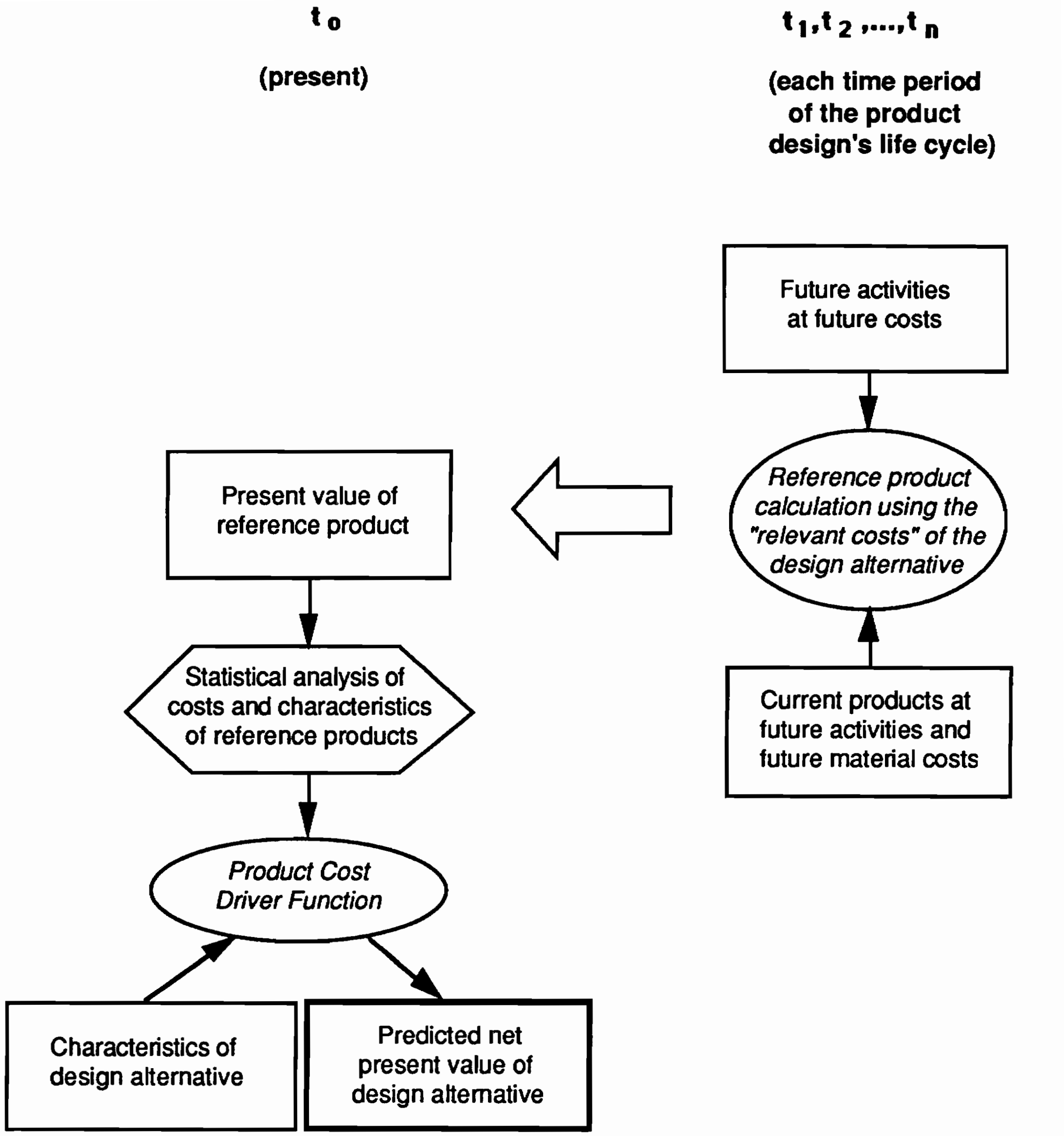


Figure 3-2: Concept of the design-concurrent calculation method

costing database are relevant for the design alternative. However, the general concept sets this method apart from a direct costing approach in which fixed cost are always left unassigned.

The present value method is applied to discount cost information of each time period to the present. The present value method has proven itself for evaluating the costs of a project and for making competing alternatives comparable [DEG88].

Based on cost calculations for reference products, similarity analysis can be applied. A regression analysis is performed on the main cost driving characteristics, whereby product characteristics are the independent variables and the present value constitutes the dependent variable. In this way a cost driver function can be determined through correlation analysis to estimate the costs of the design alternative.

The activity costing database

This section explains how costs are traced to activities to secure accurate activity cost information. It has been mentioned above that the storage of cost and other data is influenced by the requirements of the design-concurrent calculation method but that, at the same time, it has to be as neutral as possible to enable several other evaluation cases such as product abandonment, cost control, or financial reporting.

Hierarchical structure

A hierarchical, multiple-layer functional organization is used by the cost model (see Figure 3-3). This structure is used to allow a neutral recording of data. Costs can always be traced to the hierarchical level at which they are caused. Some costs can be traced directly to the lowest level such as machine depreciation, workers' salaries, or energy, while other costs can only be traced to higher hierarchical levels and might include management cost among others. This cost tracing will be further detailed later in this section.

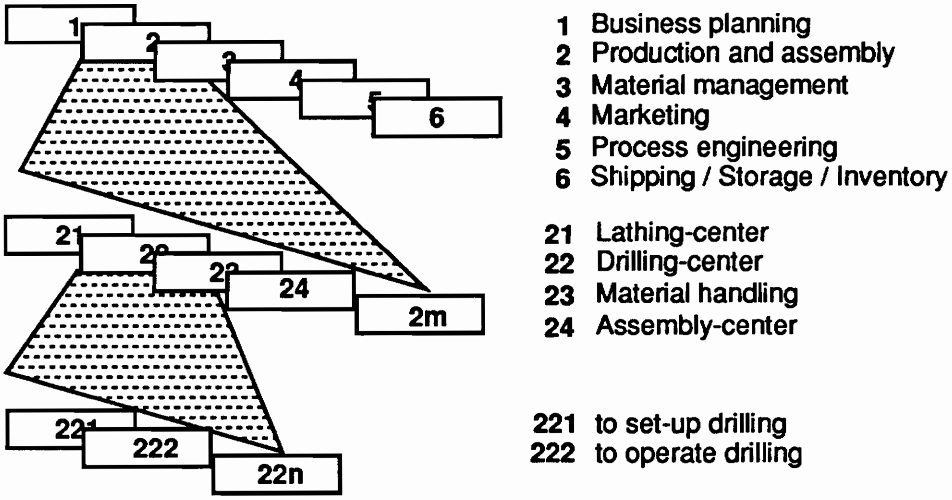


Figure 3-3: Example of a decomposed hierarchy of the production and assembly business function

Due to process investments, different activities will be performed in future time periods. The design will also utilize these future activities during its life cycle. Process investments usually add, modify, replace, or eliminate activities. Consequently, in the activity costing database the functional hierarchy may differ from one time period file to the next. For example, if an investment decision was made to introduce an NC-machine into the production process, then the activities to set-up drilling, to operate drilling, to handle material, to set-up finishing, and to finish surfaces would all be replaced by the pre-production activity to program NC-machine and the production support activities to set-up NC-machine, and to operate NC-machine (see Figure 3-4). The cost model obtains the information of which activities are replaced by which from investment planning.

activities period n

221 to set-up drilling
222 to operate drilling
231 to handle material
251 to set-up finishing
252 to finish surfaces

→

activities period n+1

263 to program NC-machine
261 to set-up NC-machine
262 to operate NC-machine

Figure 3-4: Example of an activity replacement

<u>Cost driver information</u>

For every "function" on every level of the hierarchy, a cost driver is defined to which the costs are as proportional as possible. The costs of some departments might be driven by the number of parts, e.g. in the "drilling-center," whereas some activities within this department might be driven by time, e.g. the activity "to operate drilling." A main characteristic of the activity-based approach is that a cost driver is determined for every activity. However, this concept of defining a cost driver for every function on every detail level is not common practice, although it is supported by Schmid [SCM89], Fröhlich [FRÖ90], and indirectly by Kaplan [KA89a].

Every function on every hierarchical level will be included in the product's bill of activities in the product information database, e.g., there will appear "drilling-center" on the departmental level as well as "to operate drilling" on the activity level. Therefore, in this research every function on every hierarchical level will be called "activity," whereas others have sometimes defined activities for the lowest hierarchical level only. Activity-based approaches using this latter definition of activities for the lowest level only, like the CMS-PC approach [WIE90], have to proportionalize those costs which were initially traced to higher hierarchical levels down to the lowest hierarchical level (see Figure 3-5). This procedure of cost proportionalization violates the neutral data storage principle. This violation has exposed such activity-based approaches to heavy criticism especially from Glazer [GLA91]. This problem is somewhat similar to that of the overhead allocation method in traditional volume-based approaches, which also results in distorted and misleading information.

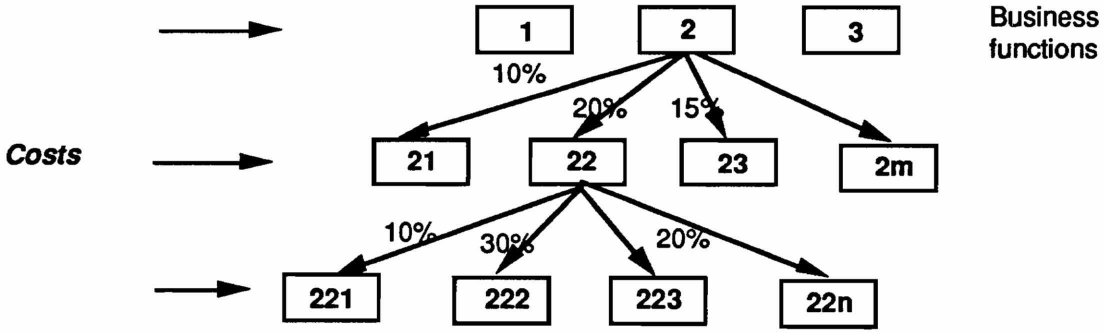


Figure 3-5: Proportionalization of costs from higher to the lowest hierarchical level which is avoided in this research

<u>Observed / planned / committed quantity of cost drivers</u>

For past periods it is possible to observe how many units of its cost driver an activity actually incurred. This information cannot be obtained as easily for future time periods. In this case the cost model determines, for every activity, how many units of its cost driver are already planned by the existing production program. This information can be retrieved from the production plan in connection with the resource consumption of the products - both are recorded in the product information database.

Special attention must be paid to the capacity committed at every activity. This committed capacity includes that required to execute the existing production schedule, as well as unused capacity. Fluctuating capacity consumption frequently leaves a considerable capacity unused (see Figure 3-6). The reason for capacity being unused at times is that capacity is not completely variable with the output. Once planned, capacity can only be reduced after certain periods of waiting time. Consequently, the associated capacity costs have to be considered fixed during these waiting time periods. Kaplan [KA91a] calls this the "long-term variability of fixed costs." Because these time periods vary among activities, the capacity costs are time-related.

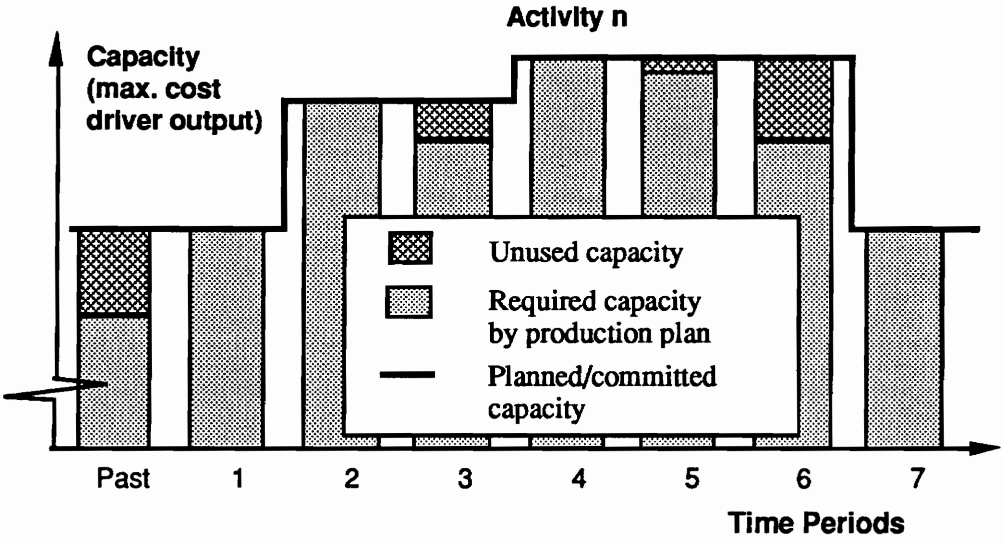


Figure 3-6: Capacity of an activity committed by the existing production program

Information about unused capacity is important for the design-concurrent calculation, because the respective costs have already been committed. Such committed costs must not be decision-relevant and, thus, must not be considered in the costing of the design.

Cost data recording

It was introduced above that costs are traced to the hierarchical level where they are caused. For past periods mainly accounting data are traced to the respective hierarchical level. However, not all the accounting data, in particular not the neutral expenses, should be used for cost evaluations while, on the other hand, some additional costs have to be considered for cost calculations that do not represent accounting expenses (see Figure 3-7).

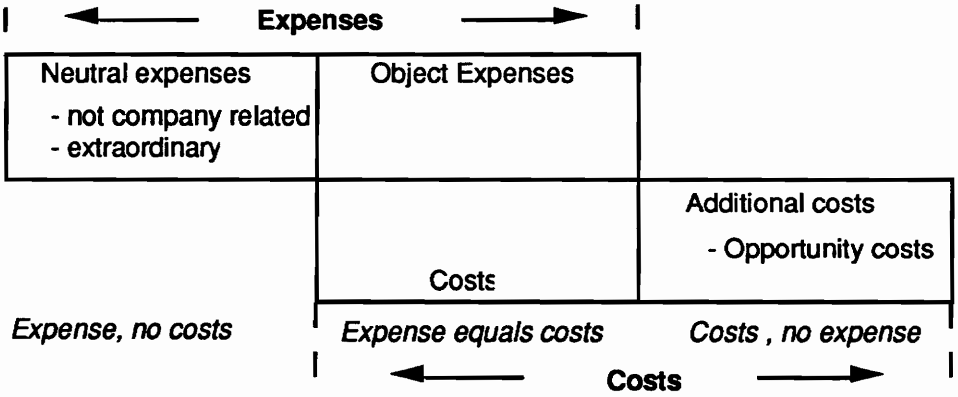


Figure 3-7: The distinction between expenses and costs

Expenses are called neutral when they are either not business-related such as donations, or when they are extraordinary, e.g. currency losses. Neutral expenses are not relevant for cost calculations and, thus, have to be excluded from consideration for cost evaluation cases such as design-concurrent calculation. Those expenses are marked in the database so that they are only considered for tax purposes. On the other hand, other costs are considered in addition to expenses. Opportunity costs such as rent for using company-owned property or interest on personally provided capital are typical additional costs. They have in common that no expenses are actually incurred. They are also marked in the database so that they can be excluded from financial reports.

All costs that are traced to an activity can be categorized as either operating costs or capacity costs. Operating costs vary directly with the units of the cost driver performed by the activity, e.g. cost of energy. The slope of the operating cost function of an activity with respect to the cost driver as its independent variable is obtained by dividing the operating costs by the cost driver output (see Figure 3-8).

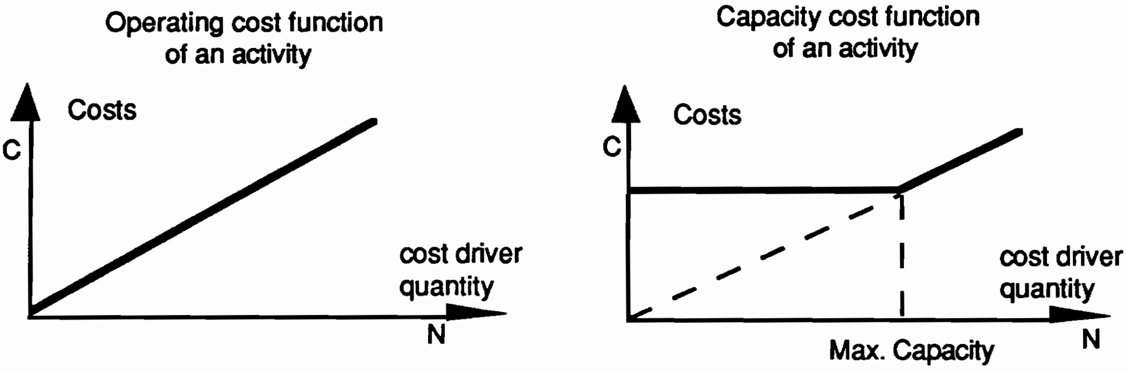


Figure 3-8: The operating cost and capacity cost functions of an activity

Capacity costs, e.g. depreciation, are incurred even if there is no production or when no cost driver is performed. Every activity's cost driver has a certain maximum capacity it can provide. If this capacity is to be increased it will impact on all capacity costs related to this activity, (e.g. a new machine also requires new workers for its operation to increase output capacity). The slope of the capacity cost function beyond the maximum capacity can be determined by dividing the existing capacity costs by the maximum capacity (see Figure 3-8).

For future time periods no accounting data is available yet. In order to record planned cost data, the cost model as a first step makes a cost prediction based on the existing production plan as well as on past costs. Then, in a second step the model is used to correct those predictions for expected cost variations.

The model predicts the planned costs by multiplying the costs per unit cost driver from the most recent period by the planned activity output for each future time period. This constitutes the first prediction of planned operating costs and capacity costs of an activity. However, these costs are aggregates because they are the sum of several costs such as depreciation, salaries etc. Therefore, the cost model separates these aggregates into their individual components by applying the same cost proportion (cost structure) as had been observed in the most recent period. This prediction by the cost model initially assumes that the costs as well as the activity cost structure will remain unchanged in the future. If the user has better information about future cost developments or changes in the cost structure, (s)he has to adjust those predictions accordingly. Then, the cost model recalculates the costs per unit cost driver, and adjusts the operating and capacity cost functions to account for the user's insights.

In case process investments result in new, replacement activities their costs would have been determined during the analysis of the replacement option. In the example on page 58, in which a drilling and a finishing machine were to be replaced by an NC-machine, investment planning would have calculated the resulting difference in total expected costs before making the replacement decision. All costs of all activities involved had to be considered including depreciation costs, and also salaries. The cost data from the replacement decision process can be directly recorded in the activity costing database.

The product information database

While the previous section has dealt with the recording of activity cost information, the focus now will be on the form in which product information is recorded. The objective, again, is to ensure neutral data storage as well as sufficient support for the design-concurrent calculation method.

Hierarchical structure

Almost all products have components and parts as subunits, which themselves can also be considered products. The one difficulty in this context is that activities, such as assembly activities or material handling, are usually necessary to produce a component from several parts. Therefore, it is not possible to simply add up the required resources of the subunits in order to obtain the product requirements (see Figure 3-9).

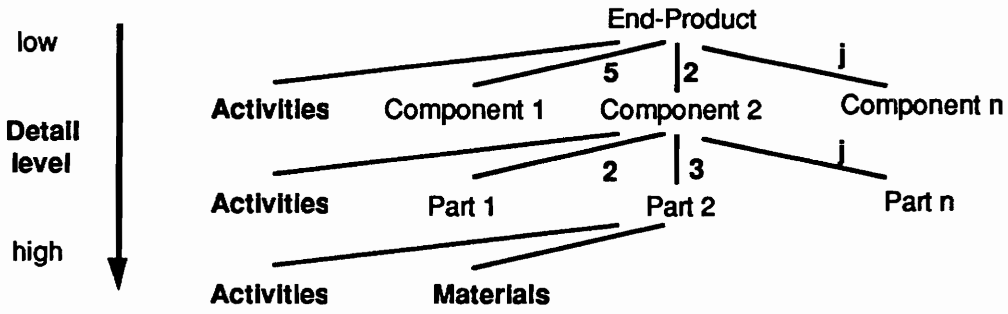


Figure 3-9: Activities and other products are required resources on every detail level

The cost model stores the products in a hierarchical structure. This means only those activities and materials that are required for a particular detail level are actually stored there. This requires information on which products are used as parts or components, as well as on their required quantities. Thus, the required activities and materials are always recorded at the highest possible detail level.

Production plan

Observed production quantity of past periods and planned production quantity of future periods are recorded in the respective file for each time unit in the database. Production quantity as well as batch-size information are included for the following two reasons. First, the required or used capacity at each activity can be derived from this production plan in connection with the bill of activities of all products. This information thereby feeds the activity costing database. Secondly, many design alternatives are re-using current parts and components. In this case the costs to increase the production quantity represent the decision-relevant costs. Even if a product will be abandoned in the future, its product information should still be recorded for future time periods, as it can act as a reference product for the similarity analysis.

Product characteristics

In general, when the cost influence of some main characteristics can be understood, a calculation of a design alternative is possible based upon those characteristics. This requires that the main characteristics of every product are recorded as part of the product information database. There has been extensive research determining the main characteristics for different products in different companies. These main cost driving characteristics of a product are very dependent on the cost structure of the company.

Product families on lower levels of detail usually have cost driving characteristics that are more concept-related, while product families at higher levels of detail have more form-specific characteristics. Every component or part will belong to only one particular product family. As an example, the characteristics for a gear could be as shown in Table 3-1.

Table 3-1 Example for possible main product characteristics of the product family "gears"

Characteristic	**Value**
diameter	5 inch
length	7 inch
material	steel (norm #451)
# of parts	8
parts complexity	medium
concept (# of wheels)	3
surface quality	medium

Activity consumption

Activities can be divided into pre-production activities and production support activities. Pre-production activities are all activities that are required to put the product in a production status, including research, process planning, and supplier search. On the other hand, production support activities are those that are necessary to actually produce the product and to sustain the product in a producible status. Lathing, engineering change orders, and shipping are examples of production support activities.

The pre-production activities only occur in early time periods of the product life cycle, while the production-support activities only occur in later time periods. Because the design-concurrent calculation method will make separate calculations for those time periods, it needs to be able to distinguish between pre-production and production-support activities.

For the design-concurrent calculation it is important to know the required activities of the reference products at different production quantities. Horvath and Renner have shown that, due to economies of scale, the amount of activities required for a single product is very dependent on the quantity which is produced. To account for economies of scale, activity-based cost systems use more types of cost drivers than conventional systems. Conventional cost systems use cost drivers (or allocation bases, as they are called there) that are proportional to the number of units that are produced (direct labor hours, machine hours, material dollars). In contrast, activity-based cost systems also use cost drivers for batch activities and product sustaining activities in addition to unit level activities (see Figure 3-10).

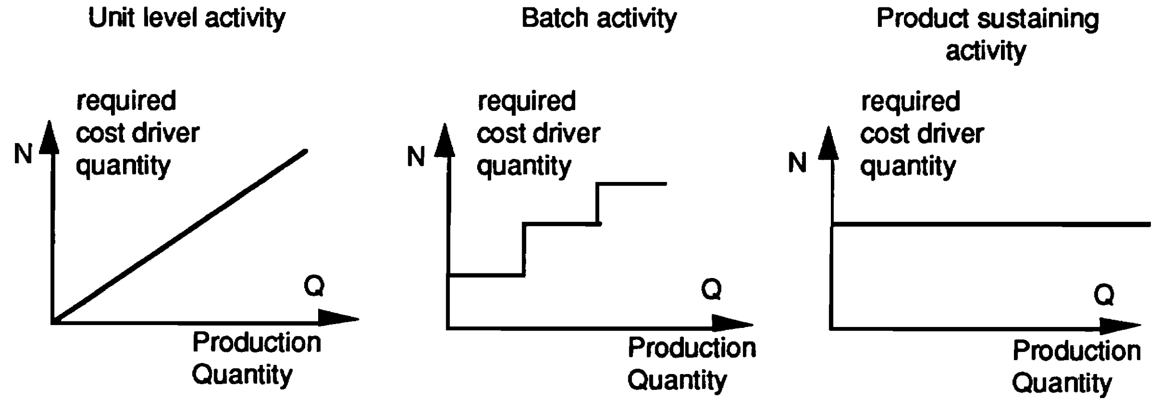


Figure 3-10: Activity consumption functions for unit level, batch, and product sustaining activities

Batch cost driver activities are required for every new batch that is manufactured, e.g. one set-up activity or a purchase order is necessary for every new batch produced. For batch activities the costs are independent of the product quantity produced on the machine, or amount of material ordered per purchase. However, as a large production quantity usually results in a separation of batches, the batch cost drivers are stepwise dependent on the production quantity. The cost driver of product sustaining activities is independent of how many items are produced in a particular period. These activities enable a company to produce a specific product. A product sustaining activity is, for example, data recording which keeps the bill of activities and the bill of material updated.

The shapes of the activity consumption functions vary with the kind of product being produced. For a unit level activity, the consumption functions vary in slope but in the case of a batch activity, different stepwise consumption functions can be observed. The steps are dependent on the batch size. They are also different across products because different quantities of the activity's cost driver are required. Finally, the constant horizontal function of a product sustaining activity also differs across products. It can be concluded that because the same activities encounter different consumption functions for different products, the individual consumption function for every product is recorded in the database. Thus, for every production quantity the required activity consumption can be derived.

Investment planning determines which old activities are replaced by new ones; and the same replacement must, in parallel, be done on the bill of activities of all products stored in the database. It is the responsibility of investment and process planning to determine the consumption functions for the different existing products when evaluating the new activities. Again, this had been a part of the investment decision process, because the consumption functions were needed in order to actually determine the expected savings.

Material costs

The amount of material required usually changes proportionally with the production quantity. Therefore, to find the total quantity of necessary material one simply has to multiply the material quantity that is required for one product by the number of products under consideration.

Material costs are also easy to deal with because they can be traced directly to products. The troublesome allocation of costs first to activities, and then via the bill of activities to the products, is not necessary. Sometimes the material consumption also has to be adjusted when introducing new activities, for example, when they reduce scrap.

The design-concurrent calculation method

This section discusses how the design-concurrent calculation method of the cost model processes the information recorded in the databases. The calculation of reference products on the basis of relevant costs is outlined in detail, as it has to be repeated for every time period. Moreover, this section presents the estimation of material costs and relevant activity consumption as well as the associated relevant costs for this consumption. Then, the present value method is utilized to discount the costs from future time periods into the present. Finally, the cost model applies the concept of similarity analysis to obtain accurate cost estimation for the design alternative based on present values. Figure 3-2 presents a conceptual view of these steps of the design-concurrent calculation method.

Decision-relevance of costs for each time period

The cost model always calculates the costs of all products that are similar to the design alternative. These products are called reference products because the design-concurrent calculation uses their product information as a reference point in its design-calculation. Reference products belong to the same product family as the design alternative, i.e., they have the same main characteristics and are located on the same hierarchical product level as the design alternative.

If the design alternative is to re-use a current product, all information about the required activities and materials is readily available. In this case, a similarity analysis is not necessary and only the respective current product needs to be considered as a reference product.

Material costs

The material costs can directly be calculated. The design quantity for each time period is simply multiplied by the material cost information recorded in the product information database.

Relevant activity cost driver quantity

For every decision-relevant activity a cost driver has to be determined that would be required for the production of the design quantity. According to the principle of relevant costs, only those cost drivers are to be considered that would be added due to the introduction of the design alternative. The required cost driver quantities will then be "priced" with the costs of the activities as they are recorded in the activity costing database.

It is typical for design alternatives to use a large number of existing products as parts or components. However, it is not known yet at most stages of the design process which parts or components are re-used because they constitute a higher design detail level and, thus, will only be specified later in the design process (see Figure 3-11).

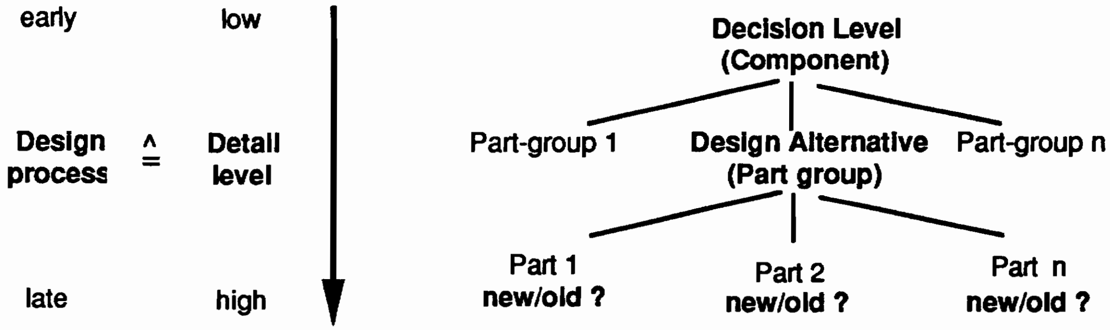


Figure 3-11: Re-used and new parts are only determined at higher detail levels reflecting later stages in the design process

The relevant activity cost driver quantity is lower for re-used parts than for newly designed parts. In order to correctly determine the relevant costs of the design alternative, the design-concurrent calculation method has to classify the alternative into a "design class." In the following, the design class is defined as the expected value-percentage of current parts to be re-used.

The design-concurrent calculation method utilizes the design classification of the design alternative as follows: For every activity it determines the relevant cost driver quantity twice. First, this quantity is determined as if the design alternative were a completely new product (N_N); then, the cost model also determines the cost driver quantity as if the design alternative were a re-used part (N_R). The relevant cost driver consumption is then estimated by assuming a linear combination of those two extreme cases:

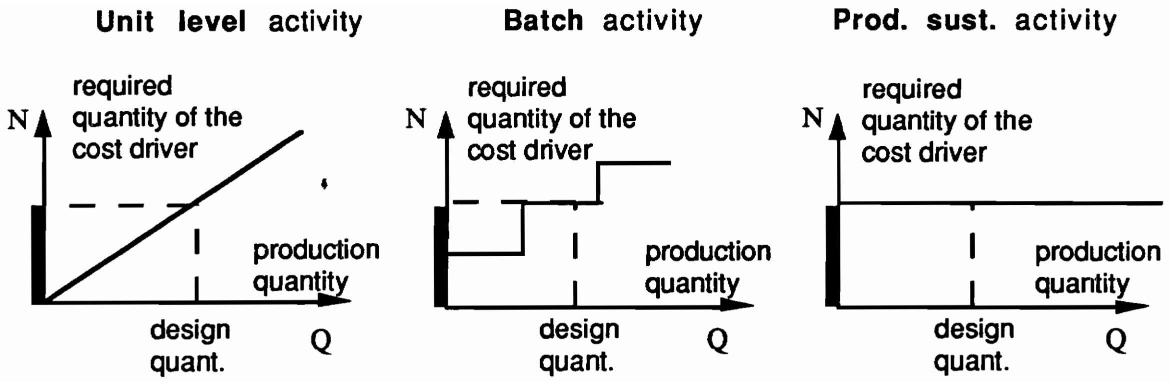
$$N = (1-C) * N_N + C * N_R \tag{4}$$

N = relevant cost driver quantity of an activity
C = fraction of the expected re-use of parts (based on part values)
N_R = relevant cost driver quantity when re-using the reference product
N_N = relevant cost driver quantity when the design is new

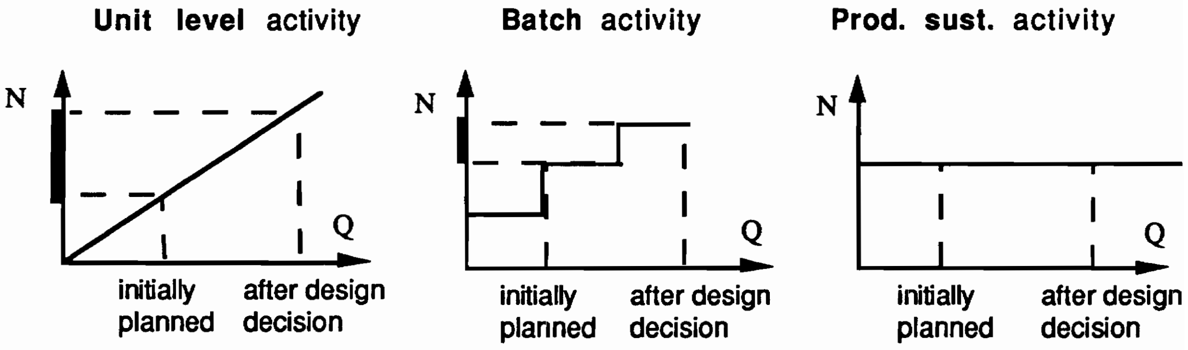
This linear combination is chosen because the activity-based approach itself assumes linear activity consumption functions as well as linear cost functions. Therefore, the assumed linearity in the above formula is not contradictory with the activity-based costing approach. The determination of the cost driver consumption for the two extreme cases, N_N and N_R, is discussed next.

Relevant cost driver quantity for a new design (N_N):

The product information database employs a functional structure. For any production quantity, the relevant quantity of activity cost drivers can be retrieved. Again, the envisioned production quantity of the design alternative at each particular time period is used to calculate the reference product and, thereby, the cost driver consumption for this quantity is determined. Figure 3-12a graphically depicts the respective functions for unit level, batch, and product sustaining activities.



a) New product development (N_N)



b) Re-use of a current product (N_R)

Figure 3-12: Activity consumption depends on whether a product is developed anew or whether it can be re-used

Relevant cost driver quantity for the re-use of the reference product (N_R):

All activities used during the pre-production time periods are irrelevant for the calculation. Note that oftentimes the introduction of new activities (investments) results in new pre-production activities. This was also the case in the example presented above in which the introduction of a new NC-machine required new NC-programming. For all current products the costs of those new pre-production activities are part of the investment costs.

The determination of the relevant cost driver quantity for production time periods has to take an incremental approach, as shown in Figure 3-12b for the three types of activities. First, the required cost driver quantity has to be determined for the sum of planned production of the reference product and design quantity. In the second step, therequired cost driver quantity is determined when following the existing production plan only. The difference of these two values is the relevant quantity of the cost driver for the N_R case.

Relevant activity costs

At this point the decision-relevant cost driver quantities for each activity have to be "priced" with the activity costs that have been recorded in the database. Because operating costs vary proportionally with the actual cost driver quantity, the costs for every cost driver are decision-relevant. Thus, operating costs always have to be considered entirely in the evaluation of design alternatives. As this case is straightforward, it will not be further considered. On the other hand, capacity costs are independent of the output quantity and require closer consideration.

Capacity requirements of the period under consideration

Costs for capacity which would have remained unused under the existing production plan are not relevant for the decision on a new design alternative. Only capacity that must be added is relevant. The cost driver quantity for this additional capacity is multiplied by the capacity costs per unit cost driver. This concept of marginally relevant costs is shown in Figure 3-13a.

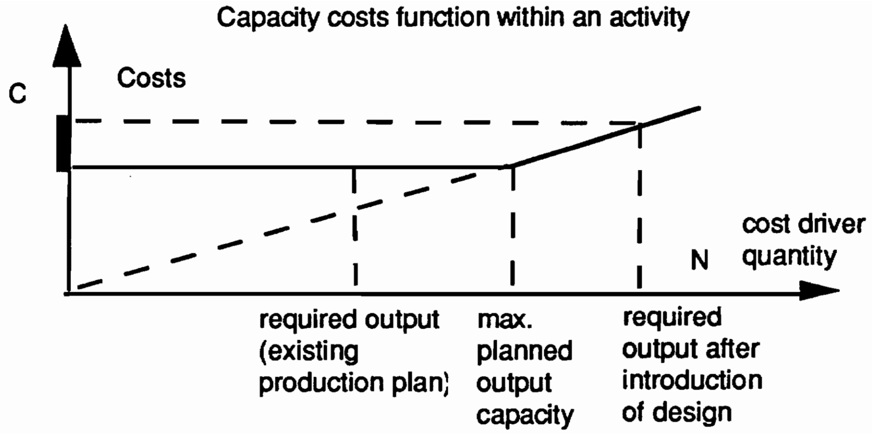
Capacity costs committed in a preceding time period

Capacities committed by the introduction of the design alternative remain fixed for certain "waiting times." Consequently, capacity costs carried over from previous time periods are also decision-relevant for the time period under consideration when the capacity remains unused (see Figure 3-13b).

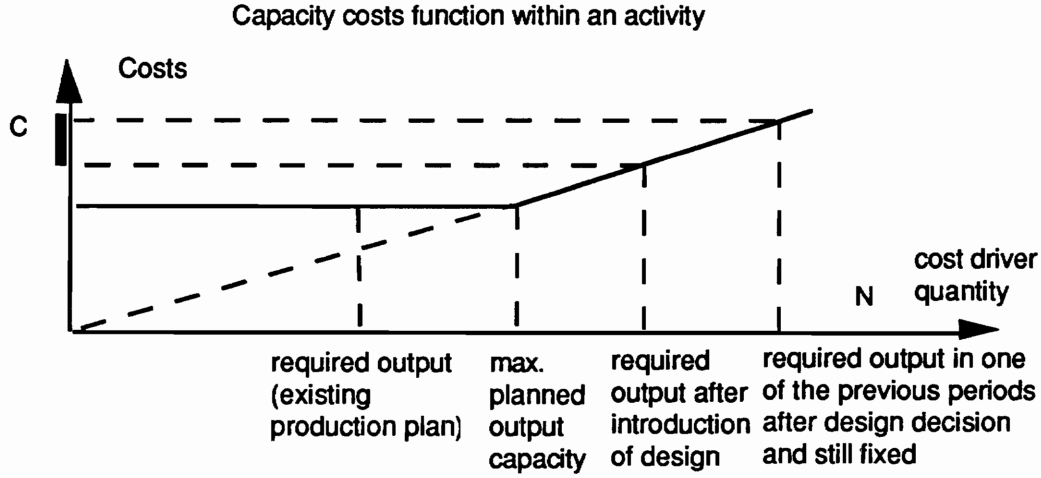
Capacity costs committed by the design are relevant for at least one time period. The one time period case occurs when the additional capacity had been planned for the following time period anyway. Then the costs are just incurred one time period earlier as a result of the design decision. Due to the fact that capacity costs from preceding time periods can be relevant, the design-concurrent calculation method not only has to estimate the costs for the time periods of the design life cycle, but also for several time periods thereafter.

Present value analysis

So far the decision-relevant costs to calculate the design alternative for a particular time period has been determined. Now, the costs of different time periods are made equivalent using the concept of the present value (PV) analysis. Because it is difficult to



a) Capacity costs required by the design in the time period under consideration



b) Capacity costs committed by the design in a preceding time period

Figure 3-13: Relevant capacity costs for the design alternative find the most appropriate discount factor for present value analysis, frequent controversies arise. Kaplan [KAP86], for example, argues on this problem as follows. "In general, a company has the option of repurchasing its common shares or retiring its debt. Therefore, decision makers can estimate the costs of capital for a project by taking a weighted average of the costs of equity and debt at the mix of capital financing. Extensive studies of the returns to investors in equity and fixed income markets during the past 60 years show that the average total return from holding a diversified portfolio of common stocks was 11.7%; ... the real return (after inflation) was about 8.5% per year. During the same time period, fixed-income securities averaged nominal before tax returns of less than 5% per year; the real return (after inflation) reduced this percentage to 1.5% per year." Considering both real costs of capital rates Kaplan [KAP86] suggests to use a discount factor of less than 8% per year for the present value analysis of a project.

Similarity analysis

With the help of similarity analysis, the cost model derives a functional relationship between the characteristics of the reference products and their costs. The costs of the design alternative can be estimated from this function.

Determining the product cost function

The characteristics and the previously obtained present value of the reference products are analyzed using ordinary least squares regression techniques. A linear function is generated that "best" fits the available data. This function helps in understanding the cost influence of the characteristics.

All the reference products have the same characteristics which was one criterion for their selection. Some characteristics are quantitative, e.g. size, or number of parts, while others are qualitative in nature, e.g. low surface quality, or medium complexity. To be able to include qualitative characteristics in the regression analysis, they are transformed into quantitative units. Care has to be taken in this transformation because it influences the position of the reference products as well as that of the design alternative within the more-dimensional characteristics table.

The regression analysis is performed with the product characteristics of the reference products being the independent variables, and their calculated costs (in present value form) being the dependent variable. The independent variables are the characteristic values as they appear in the characteristics table.

Cost estimation of the design alternative

After their transformation, the characteristics of the design alternative are inserted into the empirical cost driver function to receive an accurate present value cost estimation of the design alternative. This information is used to improve the decision process in selecting a best design alternative.

Chapter 4

CASE STUDY

A computer prototype version of the cost model, conceptually developed in the previous chapter, was coded and verified. This chapter illustrates a case study with fictitious company and product data to demonstrate the usefulness of the model. The databases as well as the reference product calculation are based on a spreadsheet program. Finally, the calculation results are analyzed using a SAS regression program [SAS85], thereby completing the design-concurrent calculation procedure (see Appendix B).

The activity costing database

Hierarchical structure

To simplify the illustration in this case study, consideration is limited to only 7 activities. In the past period file of the activity costing database, which contains the most recent cost data, the following activities are recorded: lathing (21), to set-up lathing (211), to operate lathing (212), assembly (24), to record data (251), to place an purchase order (321), and to plan (511) (see Table 4-1). The company has three hierarchical levels in this case study. The activities "assembly" and "lathing" are on the second hierarchical level whereas the others are on the third. The "planning" activity is a pre-production activity, while all others are production-support activities.

Table 4-1: The past period file of the activity costing database

Past Period	**Activities**						
Hierarchy							
ID #	21	211	212	24	251	321	511
Activity	Lathing	Set-lath.	Oper.lath.	Assembly	Rec.data	Purch.ord.	Planning
Act. Type	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Pre-prod.
Cost Driver							
Cost driver	# ord.	Time [h]	Time [h]	Time [h]	# rec.	# ord.	Time [h]
C.D. Type	Batch	Batch	Unit l.	Unit l.	Prod.sust.	Batch	
Observed ...							
Actual output	109	106	1170	798	240	621	300
Max. capacity	120	110	1250	950	240	700	300
Spare capacity	11	4	80	152	0	79	0
Waiting time	3	1	2	2	1	2	2
Rem. wait. time	2	0	1	1	0	1	1
Cost data							
Operating costs:							
Energy	2 K	10 K	60 K	20 K	20 K	5 K	15 K
Maintenance	15 K		5 K	10 K			
** Sum	17 K	10 K	65 K	30 K	20 K	5 K	15 K
Unit Cost Driver	156	94	56	38	83	8	50
Capacity costs:							
Rent				15 K		30 K	9 K
**Rent (add'l)*				20 K	8 K	8 K	
Salaries	25 K	10 K	60 K	50 K	70 K	40 K	120 K
Deprec.	15 K		20 K		15 K	8 K	20 K
** Sum	40 K	10 K	80 K	85 K	93 K	86 K	149 K
Unit Cost Driver	333	91	64	89	388	123	497

In period 4 the lathing machine will be replaced by an NC-machine. This means that on the second hierarchical level the "lathing activity (21)" is replaced by the "NC-center activity (26)" in the period 4 file of the database (see Table 4-2). On the third hierarchical level, "to set-up lathing (211)" and "to operate lathing (212)" are replaced by "to set-up NC (261)" and by "to operate NC (262)," as shown in the two tables.

Cost driver Information

The activities "lathing," "NC-center," and "to place a purchase order" have the number of orders as their cost driver, the activity "to record data" is driven by the number of records processed, and the costs of the other activities are driven by time.

"To operate lathing," "assembly," and "to operate NC" are unit-level activities, "to record data" is a product-sustaining activity, while all remaining production support activities are batch activities.

Observed / planned / committed quantity of cost drivers

For every activity in the past period file, a cost driver output is assumed in the case study which would have been observed in reality. This cost driver output is called "observed, actual output" in Table 4-1. The past period file also contains the observed maximum output capacity as well as the spare capacity, which is residual of the former two. A capacity is fixed for a certain number of waiting time periods, once it has been committed. This information is recorded under "waiting time" in the table. In general, capacity costs are oftentimes committed before the previous period, and they remain fixed for several time periods to follow. The recorded number for "remaining waiting

Table 4-2: The period 4 file of the activity costing database

Period 4	**Activities**						
Hierarchy							
ID #	24	251	26	261	262	321	511
Activity	Assembly	Rec.data	NC-center	Set-NC	Oper. NC	Purch.ord.	Planning
Act. Type	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Prod.sup.	Pre-prod.
Cost Driver							
Cost driver	Time [h]	# rec.	# ord.	Time [h]	Time [h]	# ord.	Time [h]
C.D. Type	Unit I.	Prod.sust.	Batch	Batch	Unit I.	Batch	
Planned ...							
Required output	894	240	198	20	440	1078	300
Max. capacity	960	240	198	20	440	1078	300
Spare capacity	66	0	0	0	0	0	0
Waiting time	2	1	2	1	3	2	2
Rem. wait. time	1	1	2	1	3	2	2
Cost data							
Operating costs:							
Energy	23 K	20 K	20 K	2 K	15 K	9 K	15 K
Maintenance	11 K		4 K	1 K			
** Sum	34 K	20 K	24 K	3 K	15 K	9 K	15 K
Unit Cost Driver	38	83	121	151	34	8	50
Capacity costs:							
Rent	15 K		9 K			46 K	9 K
**Rent (add'l.)*	20 K	8 K			5 K	12 K	
Salaries	80 K	100 K	43 K	7 K	30 K	62 K	160 K
Deprec.		15 K	40 K		50 K	12 K	20 K
** Sum	116 K	123 K	92 K	7 K	85 K	133 K	189 K
Unit Cost Driver	89	388	465	350	193	123	497

time" reflects the number of remaining time periods for which the respective capacity has been committed, e.g., a 2 in the past period file means that the capacity has already been committed by decisions in the past for the future time periods 1 and 2.

The required output of each activity for all future time periods is shown in Table 4-3. The required output is obtained from the existing production plan in connection with the bill of activities of all products. It is obvious from this table that the activities related to lathing after period 3 are replaced by those needed for the operation of the NC-machine.

Table 4-3: The required activity cost driver quantities for the next seven time periods

	Activities									
	21	211	212	24	251	26	261	262	321	511
Past	109	106	1170	798	240				621	300
1	87	86	1185	824	240				511	300
2	100	93	1360	952	240				534	300
3	99	96	1400	960	240				539	300
4				894	240	198	20	440	1078	300
5				1056	240	217	20	535	1115	300
6				945	240	187	18	455	979	300
7				827	240	161	15	390	845	300

Unused capacity is in common because capacity is fixed for certain time periods, while its consumption usually fluctuates. Figure 4-1 illustrates the required capacity and the unused capacity of the "assembly activity (24)" as they were generated by the cost model for the next seven future time periods. For example, in period 5 a capacity of 1,056 cost driver units is required by the production plan for this activity (see also

Table 4-3). The capacity has a waiting time of 2 time periods. Thus, the planned capacity for period 5 will automatically also be committed for the periods 6 and 7. However, for this activity the existing production plan only requires 945 and 827 units respectively of the cost driver in those two periods , i.e., unused capacity is the consequence.

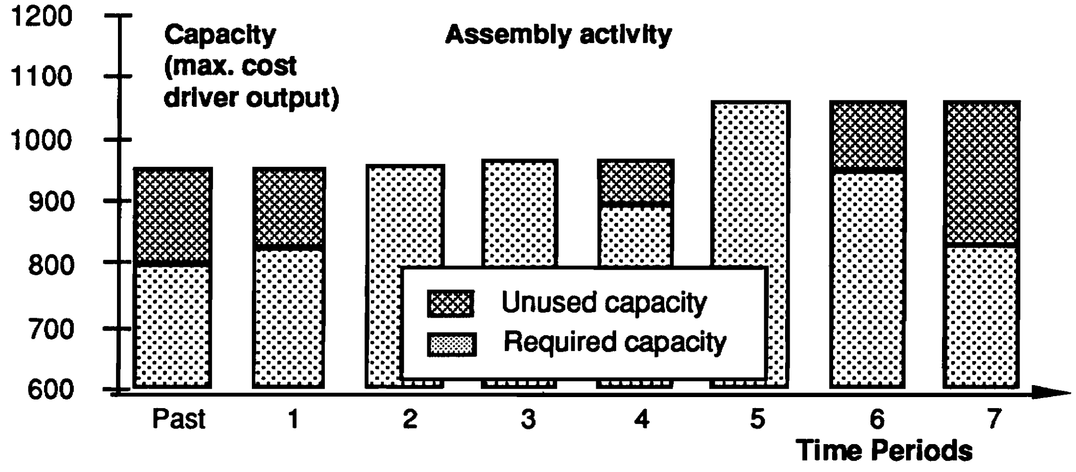


Figure 4-1: Required and unused capacity of the assembly activity for the existing production plan

Cost data recording

To simplify the illustrations, only 6 cost types are considered in the case study. They are the costs for energy, maintenance, rent, rent as an additional cost (see chapter 3 for details), salaries, and depreciation (see Tables 4-1 and 4-2). Energy and maintenance are operating costs whereas the other 4 types are capacity costs. The costs are traced to the lowest hierarchical activity level possible.

In the past period file the cost model estimates the costs per unit cost driver separately for operating and capacity costs. Costs per unit are obtained by dividing the total operating costs by the observed output and the capacity costs by the maximum capacity. For example, the operating costs for a single cost driver of the activity "assembly (24)" are $38 ($30,000 / 798), whereas the costs for the capacity unit cost driver are $89 ($85,000 / 950).

For future time period files, the cost model predicts the costs of those seven cost types based on the existing production plan in connection with cost data from the most recent period file. For the operating cost prediction, the costs per unit cost driver of the past period are multiplied by the required output. The total is divided in a next step into its components, namely cost types. This division of the total operating cost into its components is based on the cost structure of the most recent period. For example, the operating costs per unit cost driver at the assembly activity are $38 for the most recent past period. For period 4 the required output of this activity is 894. Thus, $33,972 (=$38 * 894) operating costs are predicted by the cost model for this activity in period 4. In the past period, energy costs reflected 67% (=$20,000 / $30,000) of the total operating costs. The predicted $33,972 for total operating costs now have to be multiplied by 67% to obtain predicted energy costs of approximately $22,761. Thereby, the case study assumes that the cost structure of all activities remains constant over time. The cost prediction for the individual capacity costs is performed analogously, but based on maximum planned / committed rather than required output as the initial reference. The costs of the new, replacing activities shown in Table 4-2 could be obtained from investment planning.

The product information database

Hierarchical structure

The product information database records of the reference products for the past time period file are shown in Table 4-4; the respective file for period 4 is shown in Table 4-5. In this case study a design alternative from the product family "gears" is assumed. Consequently, the reference products for the similarity analysis are taken from the same product family. It is assumed that 10 products qualify as reference products; they will subsequently be referred to as products 1 - 10. It is further assumed that the 10 reference products all have a common product structure so that they do not require other products as subunits.

Production plan

The past and planned production quantities, as they are assumed in the case study, are shown in Table 4-6. Note that the rows for the past period and for period 4 match the respective ones of Tables 4-4 and 4-5. The optimal batch size differs between the products, and is shown in Table 4-4. The introduction of the NC-machine in period 4 is assumed to reduce all batch sizes by half as indicated in Table 4-5.

Product characteristics

The reference products in the case study have three main cost driving characteristics. They are the number of parts, the value of purchased parts, and the product complexity. Only the number of parts is a quantitative characteristic, while the other two are qualitative.

Table 4-4: The past period file of the product information database

Past Period	**Products**									
Hierarchy										
ID #	1	2	3	4	5	6	7	8	9	10
Production Plan										
Quantity	250	250	450	100	150	300	100	320	200	100
Batch size	70	50	65	70	60	55	60	50	55	70
Characteristics										
Number of parts	15	21	22	17	21	11	10	14	20	16
Purchased parts value	med	high	low	low	low	med	high	high	low	med
Product complexity	med	high	med	low	high	med	high	low	low	high
Act. consumption [Cost Driver qty ...]										
Unit level [... per unit]:										
212 Oper.lath. [hours]	0.50	0.40	0.75	0.60	0.90	0.50	0.40	0.10	0.60	0.65
24 Assembly [hours]	0.30	0.60	0.50	0.20	0.60	0.10	0.20	0.20	0.40	0.40
Batch [... per batch]:										
21 Lathing [# ord]	2	1	3	3	3	2	1	1	3	2
211 Set-lath. [hours]	2.0	3.0	2.0	1.0	3.0	2.0	3.0	1.0	1.0	3.0
321 Purch.ord. [# ord]	12	17	7	7	7	12	17	17	7	12
Prod. sust. [... for all]:										
251 Rec. data [# rec.]	20	30	30	20	30	10	10	20	30	20
Pre-prod. [... for all]:										
511 Planning [hours]	80	95	80	65	95	80	95	65	65	95
Material costs [$ per unit]										
MW1 wheel	17	23	11	11	11	17	23	23	11	17
MS2 steel	15	21	9	9	9	15	21	21	9	15

Table 4-5: The period 4 file of the product information database

Period 4	**Products**									
Hierarchy										
ID #	1	2	3	4	5	6	7	8	9	10
Production Pl.										
Quantity	250	280	600	120	150	250	140	200	150	200
Batch size	35	25	23	35	30	28	30	25	28	35
Characteristics										
Number of parts	15	21	22	17	21	11	10	14	20	16
Purchased parts value	med	high	low	low	low	med	high	high	low	med
Product complexity	med	high	med	low	high	med	high	low	low	high
Act. consumption [Cost Driver qty ...]										
Unit level [... per unit]:										
24 Assembly [hours]	0.30	0.60	0.50	0.20	0.60	0.10	0.20	0.20	0.40	0.40
262 Oper. NC [hours]	0.17	0.13	0.25	0.20	0.30	0.17	0.13	0.03	0.20	0.22
Batch [... per batch]:										
26 NC-center [# ord]	2	1	3	3	3	2	1	1	3	2
261 Set-NC [hours]	0.2	0.3	0.2	0.1	0.3	0.2	0.3	0.1	0.1	0.3
321 Purch.ord. [# ord]	12	17	7	7	7	12	17	17	7	12
Prod. sust. [... for all]:										
251 Rec. data [# rec.]	20	30	30	20	30	10	10	20	30	20
Pre-prod. [... for all]:										
511 Planning [hours]	80	95	80	65	95	80	95	65	65	95
Material costs [$ per unit]										
MW1 wheel	17	23	11	11	11	17	23	23	11	17
MS2 steel	15	21	9	9	9	15	21	21	9	15

Table 4-6: The production quantities of the products

	Products									
	1	2	3	4	5	6	7	8	9	10
Past	250	250	450	100	150	300	100	320	200	100
1	250	300	450	100	150	300	100	320	200	100
2	200	320	700	80	120	300	80	300	300	90
3	290	300	650	100	130	300	100	300	200	200
4	250	280	600	120	150	250	140	200	150	200
5	150	250	750	200	170	280	200	280	250	300
6	200	300	700	100	80	250	100	250	300	180
7	150	300	500	100	150	180	100	180	300	120

Activity consumption

The reference products all require the 7 activities, as discussed above for their production. The activity consumption of the past period (see Table 4-4) remains unchanged for the periods 1, 2, and 3. However, due to the investment in period 4 the products will be produced on the NC-machine. The new activities and their estimated consumption are shown in Table 4-5.

For every product the individual consumption function is recorded in the database. For the unit-level activities, the activity consumption is recorded as the cost driver quantity required per product unit. For example, the assembly activity (24) has "time" as its cost driver. For reference product 1, 0.3 hours are stored in the database for this activity and, thus, are required to produce one unit of the product (see Table 4-4 or 4-5). The activity consumption of the batch activities is recorded as the required cost driver quantity per batch. Based on this information, in connection with the batch size, the required activity consumption can be derived for every production quantity. For example, the activity "to place a purchase order (321)" has the "number of orders" as its cost driver. Product 1 requires 12 orders for the production of each batch. Finally, product-sustaining activities are independent from the production quantity. The recorded number reflects the required cost driver quantity for one time period for any production quantity, if production takes place. For example, product 1 requires 20 data recordings in one time period in the case of production.

In the case study, the determination of the activity consumption for the reference products is driven by their characteristics. The assumed correlation between the product characteristics and the resulting resource consumption is shown in Table 4-7. (In reality only the resource consumption can be observed whereas the influence of the characteristics on the consumption is not known). For example, it is assumed that the "set-up lathing (211)" activity is positively correlated with product complexity. Product 1 has a recorded complexity of "medium," while product 2 has a complexity of "high" (see Table 4-4). The correlation matrix in Table 4-7 indicates that product 1 requires less set-up lathing activity than product 2.

Material costs

The reference products all require two materials, namely wheel (MW1) and steel (MS2), for their production. The recorded numbers in the database are the material costs in dollars per product unit. For example, a unit of product 1 needs $15 of steel. The determination of the material costs for the reference products of the case study is, again, driven by their characteristics. As it is shown in Table 4-7, the "purchased parts value" is assumed to be the only driving factor for material costs.

Table 4-7: The assumed correlation matrix between product characteristics and activity consumption / material costs

		Characteristics		
		Number of parts	Purchased parts value	Product complexity
Act.	**consumption**			
21	Lathing		-	
211	Oper. lath.		-	+
212	Set-lath.			+
24	Assembly	+		+
251	Record data	+		
26	NC-center		-	
261	set-NC			+
262	Oper. NC		-	+
321	Purch. ord.		+	
511	Planning			+
Material	**costs**			
MW1	wheel		+	
MS2	steel		+	

The design-concurrent calculation method

In the following, it is explained how the reference products are calculated based on the decision-relevant costs of the design alterative. It is assumed that the design alternative has a total life of 5 time periods. The first time period is the pre-production stage of the design, while the actual production is performed in periods 2 - 5. The planned production quantity for the second period is 350 units, it is 500 for the third period, then 400 and 200 for the periods 4 and 5. Furthermore, a design class of C=75% is assumed.

The design-concurrent calculation method separately determines the relevant costs for each time period. The reference product calculation method is demonstrated with product 1 for period 4.

Decision-relevance of costs for each time period

Material costs

400 units of the design alternative are scheduled to be produced in period 4. Based on this known production quantity, the material costs of reference product 1 can directly be determined from the respective numbers stored in the product information database (see Table 4-5). Total material costs of $12,800 (=400 * ($17 + $15)) are obtained.

Relevant cost driver quantity

The relevant activity consumption has to be determined for the two extreme cases N_N and N_R. As detailed in chapter 3, N_N assumes that all parts are designed anew, while N_R assumes that the reference product is re-used as is.

a) The relevant cost driver quantity of the unit-level activities is calculated by multiplying the design quantity by the required cost driver consumption per unit, as stored in the product information database (see Table 4-5). For example from Table 4-8, the assembly activity requires 120 cost driver units (=400 * 0.3). In the N_N case, the design quantity of 400 requires 12 production batches for reference product 1's optimal batch size of 35. The activity "to place a purchase order" is required 12 times per batch, as shown in Table 4-5. Thus, 144 units of the cost driver "number of orders" are necessary. Finally, for the product-sustaining activity "data recording (25)" the relevant cost driver quantity is independent from the production quantity; i.e., a constant 20 records are required. The "planning activity (511)" is a pre-production activity which makes it irrelevant for all production time periods, including period 4.

b) The relevant activity consumption in the N_R case is the additionally created activity consumption if the design alternative were added to the existing production program. The already planned production quantity for reference product 1 is 250 units. Thus, together with the design quantity of 400 units the total production quantity is 650 units.

The relevant cost driver quantity for unit-level activities is the same as in the N_N case, but its determination is different. For example, the assembly activity requires 195 hours of the cost driver time to produce the total of 650 units. Seventy-five of those

Table 4-8: The determination of the decision-relevant cost driver quantity in period 4 for reference product 1

Period 4 Reference Product 1

Relevant cost driver quantity

	a) NN	*b) NR*	*c) weighted average*
Planned Quant.	0	250	
Batch size	35	35	
Design Quant.	400	400	
Pre-production	0	0	
Design Class			75%
Activities			
- Unit level:			
24 Assembly [hours]	120	120	120
262 Oper. NC [hours]	67	67	67
- Batch:			
26 NC-center [# ord]	24	22	23
261 Set-NC [hours]	2	2	3
321 Purch.ord. [# ord]	144	132	135
- Prod. sustaining:			
251 Rec. data [# rec]	20	0	5
- Pre-production:			
511 Planning [hours]	0	0	0

hours had already been planned by the existing production plan, i.e., only the incremental 120 hours are decision-relevant. At a batch size of 35 units, 19 batches are necessary to produce 650 units. For the planned production of 250 units, 8 batches were already required so that only the additional 11 batches are decision-relevant for batch activities. For example, the batch activity "to place a purchase order" requires in the N_R case only 132 (=11 * 12) cost driver units, while 144 units were needed in the new design case (N_N) described above. At the "record data" activity the decision to re-use the product does not commit any additional consumption because it would have been performed anyway. This is typical for product-sustaining activities in the N_R case.

c) As mentioned, a design class of C=75% is assumed for this case study. To calculate the decision-relevant costs of reference product 1 the weighted average of the aforementioned two extreme cases N_N (weight 25%) and N_R (weight 75%) is taken. For example, the activity consumption of the activity "to place a purchase order" is estimated with 135 units of the cost driver (=144 * 0.25 + 132 * 0.75).

Relevant costs of an activity

For all activities the required quantities of their cost driver were determined in the previous step. Now, the total decision-relevant costs of those cost drivers are estimated (see Table 4-9). The following description focuses on the "assembly activity (24)."

a) Reference product 1 requires 120 units of the cost driver "time" in period 4 for its assembly activity (see Table 4-8). The operating costs for 120 cost driver units are $4,512 as shown in Table 4-9. They are calculated by the cost model from the cost

Table 4-9: The determination of the decision-relevant costs in period 4 for reference product 1

Period 4 **Reference product 1**

Relevant activity costs

ID #	21	211	212	24	251	26	261	262	321	511	Sum
Activity	Lathing	Oper.lath.	Set-lath.	Assembly	Rec. data	NC-center	Set-NC	Oper. NC	Purch.Ord.	Planning	
Cost Driver	# ord.	Time [h]	Time [h]	Time [h]	# rec.	# ord.	Time [h]	Time [h]	# ord.	Time [h]	
a) Planned operating costs											
Req. output				120	5	23	3	67	135	0	
Oper. costs				$4,512	$417	$2,788	$452	$2,283	$1,087	$0	$11,539
b) Planned capacity costs											
Req. output				120	5	23	3	67	135	0	
Spare cap.				66	0	0	0	0	0	0	
Cap. increase				54	5	23	3	67	135	0	
Cap. costs				$4,814	$1,938	$10,687	$1,050	$12,934	$16,586	$0	$48,008
c) Capacity costs committed in a preceding period											
Max. cap.	114	1650	111	1110	245	221	23	507	1213	300	
Req. cap.	99	1400	96	1014	245	221	23	507	1213	300	
Spare cap.	15	250	15	96	0	0	0	0	0	0	
Cap. costs	$5,000	$16,000	$1,364	$8,607	$0	$0	$0	$0	$0	$0	$30,971
											$90,518

driver's unit operating costs of $37.60 (a rounded value of $38 is shown Table 4-2) multiplied by the required quantity of 120.

b) For the assembly activity 66 hours of spare capacity have been predicted by the cost model and recorded in the activity costing database (see Table 4-2). These 66 units of the cost driver are available to the design without generating decision-relevant costs. However, the activity's total capacity needs to be increased by 54 (=120 - 66) cost driver units. The capacity costs for this increase are calculated to be $4,814 based on the estimated costs per unit cost driver of $89.15.

c) In time period 3, the capacity had to be increased to 1,110 cost driver units due to the production of the design alternative. This capacity had already been committed as fixed costs for the period 4 considered here. However, the design alternative requires only 1,014 cost driver units in period 4, with 96 units expected to be idle. The associated costs for this spare capacity are estimated to be $8,607 (=96 * $89.15) and are decision-relevant in this time period 4.

The planned and committed capacity based on the existing production plan (identical to that shown in Figure 4-1), the committed capacity by the design alternative from a preceding period, as well as the required additional capacity by the design alternative for the respective time period, are all illustrated in Figure 4-2. The area labeled "capacity planned/committed by the design" for period 4 reflects graphically what has been described in part b) of this paragraph. Accordingly, part c) is matched by the area marked "capacity committed by the design in a preceding period."

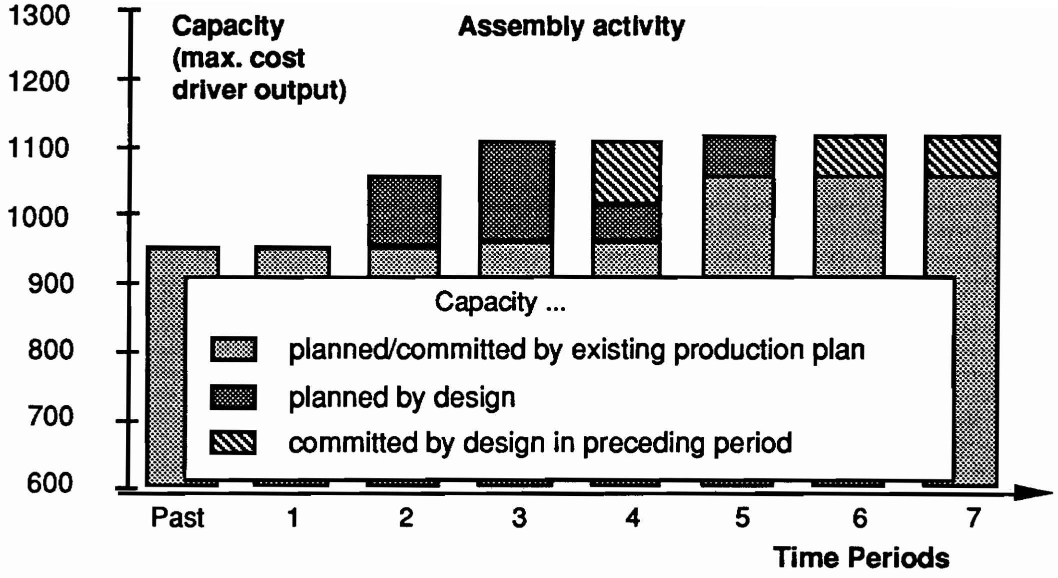


Figure 4-2: Planned / committed capacity by the existing production plan and by reference product 1 for the assembly activity

Present value analysis

The present value (PV) is calculated for all reference products based on their design-decision costs. An interest rate of 8% is assumed for discounting in this case study. Total relevant costs for each of the seven time periods along with the resulting PV are shown for reference product 1 in Table 4-10. Note, that activity costs are incurred in period 1 and in periods 6 and 7, although no production was in place. The costs in period 1 result from the pre-production planning activity, whereas in periods 6 and 7 capacity costs from earlier time periods have to be considered.

Table 4-10: The design-decision costs for each period and the resulting present value of reference product 1

				Time periods				
	Present	1	2	3	4	5	6	7
Design Quant.			350	500	400	200		
Material costs		0.0 K	11.2 K	16.0 K	12.8 K	6.4 K		
Activity costs		11.9 K	57.8 K	82.7 K	90.5 K	58.6 K	33.9 K	16.8 K
*** Sum		11.9 K	69.0 K	98.7 K	103.3 K	65.0 K	33.9 K	16.8 K
PV (at 8%)	$299,074							
PV per unit	$206							

Similarity analysis

Determining the product cost driver function

Based on the present values of the reference products, the costs for the design alternative are now estimated with the similarity analysis. In the case study two product cost driving characteristics are qualitative in nature. In order to include them in the regression analysis, they are first transformed to a 0 - 1 scale. A characteristic of low is transformed to zero, a medium to 0.5, and a high to one. The characteristics table and the calculated PV per unit for each of the 10 reference products is summarized in Table 4-11.

Table 4-11: Transformed characteristics and estimated present value per unit of the reference products

	Reference Products									
	1	2	3	4	5	6	7	8	9	10
X1	15	21	22	17	21	11	10	14	20	16
X2	0.5	1	0	0	0	0.5	1	1	0	0.5
X3	0.5	1	0.5	0	1	0.5	1	0	0	1
Y	$206	$272	$272	$235	$302	$235	$240	$208	$257	$267

The ordinary least squares regression analysis is performed with characteristics being the independent variables, and the present value of the costs being the dependent variable (see Appendix B for the SAS code used). The following product cost driver function is obtained as the best fit for the case study data.

$$Y = 178.3 + 3.41 X_1 - 23.63 X_2 + 45.04 X3$$

Y = Estimated present value costs

X_i = Input of characteristic i $\quad$ $i = 1,2,3$

The R^2 of 0.82 for the above regression equation indicates that 82% of the cost variability is explained by the three cost drivers included in the regression model.

Cost estimation of the design alternative

The assumed characteristics of the design alternative are shown in Table 4-12. To estimate the PV of the unit costs for the design alternative, its transformed characteristic values are inserted in the above product cost driver function. For the example, a net-present cost value of $249 can be expected for the design alternative.

Table 4-12: The characteristics of the design alternative

Characteristic	**Value**	**Transformed Value**
Number of parts	14	14
Purchased parts-value	low	0
Product complexity	med	0.5

Chapter 5

CONCLUSIONS

Summary

The information needed to make selections among competing design alternatives is usually not readily available to the designer. To avoid the adverse consequences from making flawed design decisions, it is absolutely critical to provide the designer with correct and appropriately prepared information. The cost model presented in this thesis is one approach to provide more accurate cost information in the design stage. In this thesis not only was the cost model developed conceptually but, in addition, the model was then implemented for an illustrative case study.

The cost model integrates the similarity analysis method and an activity-based cost management system. The literature has shown that similarity analysis is a successful approach for design-concurrent calculation. The activity-based approach presented in this research is significantly enhanced over similar approaches in its method to provide costs for decision making purposes. Moreover, it adopts the "principle of identity" which considers those costs that are relevant for a certain decision, while also using planned data in conjunction with the dynamic product calculation method to properly account for the life cycle costs of a product design. Overall, the cost model developed and presented in this thesis provides accurate cost information of product designs for decision making purposes.

The extensive literature review presented in chapter 2 positioned this research within the current state of knowledge. Current research is still lacking concerning the integration of cost-efficient designing and cost management practices. This work presents a first step towards addressing this need.

The particular contribution of the cost model lies in the way the reference products are calculated for the similarity analysis. In particular, the reference products are calculated using design-decision costs, i.e., they are calculated as if they were the design alternative. A data recording structure was developed first to enable such calculations, and a design-concurrent calculation method was then presented that can take advantage of this special data recording structure.

Relevance

Current cost models for design-concurrent calculation that rely on the similarity analysis frequently cannot benefit from accurate reference product cost information. Their problem is the reliance on financial accounting data which uses volume-based overhead allocation for the reference product calculation. The engineering economy profession often criticized that far too many evaluation cases depend on these, for decisions inaccurate input data (see chapter 2). However, recently a paradigm shift is taking place within the engineering economy [SU91a], with the emphasis now moving towards providing more accurate and timely data for engineering decisions. This research supports this new paradigm. Many of the new ideas that have emerged in this area such as the activity-based approach, life cycle costing, cost drivers, and long-term variable costs among others have been incorporated in the cost model of this research.

The reference product calculation for the design-decision costs is very dissimilar from financial accounting procedures. Its focus is on the activities that are required for the production of the design alternative, because the performance of those activities is generating the costs in a company. And it is the designer who determines the use of the activities by the geometry and the materials of his/her design.

Classical design guidelines such as "reduction of the number of parts," "re-using parts," or "designing according to available and planned processes" are made quantifiable in their cost influence by the cost model. This has not been accomplished by current models whose volume-based reference product calculation is hiding or distorting important information related to these guidelines by their overhead allocation.

The design-concurrent calculation of the cost model is tailored towards the status of the company. In its calculations the model accounts for planned utilization levels of activities as well as for the existing production plan. The designer has to find the product form with lowest production costs over its life cycle. This optimal design is very dependent on the present and future status of the company with respect to the production of other products. In some instances it might be advantageous for a design to use a smaller number but more sophisticated parts, while in other cases the opposite design is preferred. This apparent interaction between different products and different activities within a company requires a cost model as involved and, at the same time, as flexible as the one presented in this thesis.

The product design according to available and planned processes, and according to the company status has often been discussed in the "concurrent-engineering" approach. However, most concurrent-engineering research has focused on optimizing the technical and functional properties of a product design according to these aspects. The cost model, on the other hand, is one of the few concurrent-engineering models that support the optimization of a product design from an economical perspective.

Furthermore, the cost model provides a basis for other engineering evaluation cases like investment planning, product and process abandonment, and cost control among many others. The cost model's general architecture, using two databases that allow a neutral data recording scheme and that retrieve data dependent on the evaluation case, was chosen to permit such future expansions.

On the other hand, it remains uncertain to what extend companies are willing to accept further expenditures for additional data recording which is required for obtaining the more accurate decision data. However, such improved decision data would certainly reduce the discussions about data validity, and thereby shift the focus more towards their actual evaluation and subsequent actions.

Future research recommendation

From a more theoretical perspective, research efforts should evaluate additional or other techniques to improve the similarity analysis method itself. The cost estimation of a design alternative will be the more accurate the better the cost influence of the product characteristics can be understood. In the cost model of this research, only simple linear regression was used for the similarity analysis. The regression literature, however, offers many other, including nonlinear models that should be considered to possibly further improve the design-concurrent calculation method. In the same context, it should be considered to only use "closest neighbors" of the design alternative, thereby eliminating very different products of the same product family from the analyses. Such very different products could be outliners in a regression context with potentially high leverage on the regression line. One method for finding the "closest neighbors" in the multiple dimensional characteristics table is the Cluster Analysis [ECK80].

As an alternative to regression models altogether, neural networks, a modern artificial intelligence technique, could be used for the similarity analysis. Neural network have shown superior performance over classical OLS regression especially in higher-dimensional input spaces [HEC90]. Backpropagation, as one of the most common network configurations, seems very applicable to similarity analysis. Backpropagation networks are characterized by "supervised learning" which in this context would be performed on data of the reference products. In the so-called "recall-phase" the network would make an accurate cost prediction based on the product characteristics of the design alternative it is presented with.

One decisive advantage of artificial neural networks for similarity analysis is its robustness in the presence of multicollinearity. The cost driver which provide the inputs for the similarity analysis are oftentimes highly correlated with significant deleterious effects on the performance of classical regression methods. Another problem faced by the regression technique is that of "underfitting" or "overfitting" the model resulting in bias or variance respectively. This matter is of particular concern because the number of reference products are different for every design-concurrent calculation. On the other hand, underfitting or overfitting are of no concern when using a neural network.

In general, no matter whether regression or neural networks are used for the similarity analysis more research is needed to determine how many characteristics and reference products are required for an accurate cost estimation.

Predictions for future time periods and the cost estimation for the design-concurrent calculation is such a prediction and always carries some uncertainty. Research could enhance the design-concurrent calculation method by including a risk analysis. Then, the cost model could provide cost sensitivity information to certain future events. Extensive research in the area of investment theory has dealt with the risk analysis of projects [DEG88].

Another area of interest for future work could be the reliable determination of main cost driving characteristics for the different product families. Their accurate determination is critical for any design-concurrent calculation method.

In another step beyond this research, the cost model should be integrated into an inclusive concept of information processing. For example, in a CIM environment the model could be fed automatically with information about expenses as well as about planning and controlling data. Such a model should be designed according to the relational database structure which had been set as a CIM standard. Another advantage of using relational databases is the ease to add datafiles to the existing architecture to enhance the cost model's flexibility. See, for example, Sinzig [SIN85], Schmidt [SCM89] and Haun [HAU87] for current research using relational databases for cost management.

A more pragmatic area for future research encompasses practitioner issues. No actual company implementation was studied in this research. Consequently, the applicability of the cost model still needs to be confirmed. It is therefore necessary that the concepts are tested on a wide variety of "real" companies with "real" data. This also includes the collection of data in an effort to determine realistic activity cost functions as well as product consumption functions. Results of such research might question the "linearity" currently assumed in the activity-based approach (and in the cost model).

A final area of future work is to continue with the basic theme of this thesis, namely providing accurate data for decision making purposes. Additional engineering evaluation methods could be examined to fit in the general database / method architecture of the cost model developed in this research.

References

AHL88 Ahlert (1988), "Industrielle Kostenrechnung," VDI Verlag.

BAN90 Banker et al., "Costs of product and process complexity," Measures for Manufacturing Excellence (1990), Harvard Business School Press.

BÄS87 Bässler, "Integration der montagegerechten Produktgestaltung in den Konstruktionsprozeß," Dissertation Stuttgart 1987, VDI-Verlag.

BEC90 Becker, "Entwurfs- und konstruktionsbegleitende Kalkulation," Kostenrechnungspraxis, Jun. 1990, 353-359.

BER88 Berliner and Brimson (1988), "Cost Management for Advanced Manufacturing," Harvard Business School Press.

BOO88 Boothroyd and Dewhorst, "Product Design for Manufacture and Assembly," Manufacturing Engineering, Apr. 1988, 42-46.

BOO89 Boothroyd and Radovanovic, "Estimating the Cost of Machined Components During the Conceptual Design of a Product," Annals of the CIRP, Jan. 1989, 157-160.

BOR90 Borden, "Performance measurement and product costing in the AMT environment: A literature review," Selection and Evaluation of Advanced Manufacturing Technologies (1990), Springer Verlag.

BRA88 Brachtendorf, "Konzeption eines Informationssystems für die fertigungsgerechte Konstruktion," Dissertation Aachen (1987), VDI-Verlag.

BRI86 Brimson, "How Advanced Manufacturing Technologies are reshaping Cost Management," Management Accounting, Mar. 1986, 25-29.

BRI91 Brimson (1991), "Activity Cost Accounting: An Activity based Approach," John Wiley & Son.

BUL90 Bullinger, "Cost Benefits Analysis-a Major Management Tool," unpublished paper, 1990.

CLA23 Clark (1923), "Studies in the Economics of Overhead Costs,"

CO88a Cooper and Kaplan, "How cost accounting distorts product costs," Management Accounting, Apr. 1988, 20-26.

CO88b Cooper and Kaplan, "Measure Costs Right; Make The Right Decisions," Harvard Business Review, Sep./Oct. 1988, 96-103.

COO90 Cooper and Turney, "Internally focused activity-based cost system," Measures for Manufacturing Excellence (1990), Harvard Business School Press.

CRE90 Creese and Moore, "Cost modeling for concurrent engineering," Cost Engineering, Jun. 1990, 23-26.

DEA36 Deal, "Statistical Determination of Costs," University of Chicago Studies in Business Administration, Dec. 1936,

DEG88 DeGarmo, Sullivan and Bontadelli (1988), "Engineering Economy," Macmillan Publishing Company.

DIL85 Dilts and Russel, "Accounting for the Factory of the Future," Management Accounting, Apr. 1985, 30-40.

EBE90 Ebert (1990), "Controlling," Verlag Moderne Industrie.

ECK80 Eckes and Roßbach (1980), "Clusteranalysen," Kohlhammer Verlag.

EHR80 Ehrlenspiel, "Möglichkeiten zum Senken der Produktkosten - Erkenntnisse aus einer Auswertung von Wertanalysen," Konstruktion, May 1980, 173-178.

EHR85 Ehrlenspiel (1985), "Kostengünstig Konstruieren," Springer Verlag.

EHR89 Ehrlenspiel, "Kostengünstig Konstruieren," Lecture-notes University of Munich 1989.

EIS89 Eisele, "Konzeption und Wirtschaftlichkeit rechnerintegrierter Planungssysteme," Dissertation Berlin 1989, Hanser Verlag.

FLA88 Flatau, "Designing an Information System for Integrated Manufacturing Systems," Design and analysis of integrated manufacturing systems (1988), National Academie Press.

FRA90 Franzke, "Fundamentals of Value Engineering: The Value Engineering Workshop," Philips seminar 1991.

FRÖ90 Fröhlich and Krause, "Systematisches Gemeinkostenmanagement durch integrierte DV-gestützte Prozeßkostenrechnung," Kostenrechnungspraxis, Apr. 1990, 223-228.

FRÖ91 Fröhlich, "DV-Gestützte Prozeßkostenrechnung - Entwicklungsstand und Perspektiven," Controller Magazin, Mar. 1991, 117-127.

GLA91 Glaser, "Prozeßkostenrechnung als Kontroll- und Entscheidungsinstrument," Paper Draft Jul. 1991.

GRÖ91 Gröner, "Konstruktionsbegleitende Vorkalkulation," Dissertation Saarbrücken 1991, Springer Verlag.

HAU87 Haun, "Entscheidungsorientiertes Rechnungswesen mit Daten- und Methodenbanken," Dissertation Nürnberg 1987, Springer Verlag.

HEC90 Hecht-Nielsen (1990), "Neurocomputing," Addison-Wesley Publishing Company.

HIL86 Hillebrand and Ehrlenspiel, "Suchkalkulation- ein Hilfsmittel zum kostengünstigen Konstruieren," CAD-CAM Report, Jan. 1986, 53-57.

HOZ76 Horowitz, "Engineering Economy: A Economist's Perspective," AIIE Transactions, Dec. 1976, 430-442.

HOR89 Horvath and Mayer, "Prozeßkostenrechnung - Der neue Weg zu mehr Kostentransparenz und wirkungsvolleren Unternehmensstrategien," Controlling, Jul. 1989, 214-219.

HOR90 Horvath and Renner, "Prozeßkostenrechnung - Konzept, Realisierungsschritte und erste Erfahrungen," Kostenrechnungspraxis, May 1990, 307-312.

HOW87 Howell and Soucy, "The new manufacturing environment: Major Trends For Management Accounting," Management Accounting, Jul. 1987, 21-27.

HUT89 Huthwaite and Spence, "The power of Cost Measurement in New Product Development," National Productivity Review, Summer 1989, 239-248.

JO87a Johnson, "The Decline of Cost Management: a Reinterpretation of 20th Century Cost Accounting," Journal of Cost Management, Spring 1987, 5-12.

JO87b Johnson and Kaplan, "The Rise and Fall of Management Accounting," Management Accounting, Jan. 1987, 22-30.

JOH88 Johnson, "Activity based information: A blueprint for world class management accounting," Management Accounting, Jun. 1988, 23-30.

JOH91 Johnson, "Activity-Based Management: Past, Present, and Future," The Engineering Economist, Spring 1991, 219-238.

KAP84 Kaplan, "Yesterday's accounting undermines production," Harvard Business Review, Jul./Aug. 1984, 95-101.

KAP86 Kaplan, "Must CIM be justified by faith alone ?," Harvard Business Review, Mar./Apr. 1986, 87-95.

KAP88 Kaplan, "One cost system isn't enough," Harvard Business Review, Jan./Feb. 1988, 142-150.

KA89a Kaplan (1989), "Advanced management accounting," Prentice-Hall Inc.

KA89b Kaplan, "Contribution Margin Analysis: No Longer Relevant/ Strategic Cost Management: The New Paradigm," Presentation at the 1989 Annual American Accounting Association.

KA89c Kaplan, "Management accounting for advanced technological environments," Science Articles, Aug. 1989, 819-823.

KA90a Kaplan, "The four Stage model of Cost Systems Design," Management Accounting, Aug. 1990, 22-26.

KA90b Kaplan, "Limitations of cost accounting in advanced manufacturing environments," Measures for Manufacturing Excellence (1990), Harvard Business School Press.

KA91a Kaplan and Cooper, "The Current Status of Activity-Based Costing - An Interview," Management Accounting, Sep. 1991, 22-26.

KA91b Kaplan, "New Systems for Measurement and Control," The Engineering Economist, Spring 1991, 187-199.

KIL84 Kilger, "Die Konzeption einer Grundrechnung als Grundlage einer datenbankorientierten Kostenrechnung," Rechnungswesen und EDV, 5. Saarbrücker Arbeitstagung 1984, 411-434.

LIP90 Lippa, "Measuring Performance with Synchronous Management," Management Accounting, Feb. 1990, 54-59.

MAY90 Mayer, "Prozeßkostenrechnung - Rückschritt oder neuer Weg?," Controlling, Sep./Oct. 1990, 274-275.

MÄN82 Männel (1982), "Moderne Verfahren und Systeme der Kosten- und Leistungsrechnung," FernUniversität Hagen.

MIC89 Michaels and Wood (1989), "Design to Cost," Wiley & Son.

MIL85 Miller and Vollmann, "The Hidden Factory," Harvard Business Review, Sep./Oct. 1985, 142-150.

NOB90 Noble and Tauchoco, "Concurrent design and economic justification in developing a product," Intern. Journal of Prod. Research, Sep. 1990, 1225-1238.

OPI63 Opitz (1963), "Werkstücksystematik und Teilefamilien - Ein Weg zur Kostensenkung bei Konstruktion und Fertigung," Girardet Verlag.

OST90 Ostrenga, "Activities: The focal point of total cost management," Management Accounting, Feb. 1990, 42-49.

PAH82 Pahl and Rieg, "Kostenwachstumsgesetze nach Ähnlichkeitsbeziehungen für Baureihen," VDI Berichte 457, 1982, 61-69.

PAT91 Patterson, "Break-Even-Time and Time-To-Market Considerations," presentation at CAM-I CMS conference, Sep. 1991,

PIC89 Pickel, "Kostenmodelle als Hilfsmittel zum Kostengünstigen Konstruieren," Dissertation München 1989, Hanser Verlag.

PRY88 Pryor, "Updating Cost Management: The CAM-I Cost Management System (CMS) Approach," CAM-I Report.

REI90 Reichmann, Schwellnuß and Fröhlich, "Fixkostenorientierte Plankostenrechnung - Kostentransparenz und Entscheidungsrelevanz gleichermaßen sicherstellen," Controlling, Mar. 1990, 60-67.

RIE85 Riebel (1985), "Einzelkosten- und Deckungsbeitragsrechnung," Gabler Verlag.

SCH91 Schaal, "Ways to Smarter CAD-Systems - Exemplified Through Design-Concurrent Calculation," Draft of Dissertation München 1991.

SCE90 Scheer and Bock, " Konzeption eines Rahmensystems für einen universellen Konstruktionsberater," Information Management, Jan. 1990, 70-78.

SCM89 Schmidt, "Konzeption eines Kostenmodells für integrierte Systeme, gezeigt am Beispiel flexibler Fertigungssysteme," Dissertation Aachen 1989, VDI Verlag.

SCB91 Schonberger, "Lurking Issues in Cost Management," Journal of Cost Management, Summer 1991, 3-6.

SEI91 Seidenschwarz. "Target Costing - Ein japanischer Ansatz für das Kostenmanagement," Controlling, Jul./Aug. 1991, 198-203.

SIN85 Sinzig, "Datenbankorientiertes Rechnungswesen," Dissertation Nürnberg 1985, Springer Verlag.

STO83 Stobaugh and Telesio, "Match manufacturing policies and product strategy," Harvard Business School Review, Mar./Apr. 1983, 113-120.

SU91a Sullivan, "A New Paradigm for Engineering Economy," The Engineering Economist, Spring 1991, 187-199.

SU91b Sullivan, "Target Costing in an Activity-Based Environment," unpublished paper, 1991.

SUR89 Suri and Shimizu, "Design for analysis: a new strategy to improve the design process," Research in Engineering Design, Jan. 1989, 105-120.

THU89 Thuesen and Fabrycky (1989), "Engineering Economy," Prenctice Hall.

TIP87 Tipnis, "Process and economic models for manufacturing operations," Design and Analysis of Integrated Manufacturing Systems (1987), National Academy of Engineering.

TUR89 Turney, "Using Activity-Based Costing to Achieve Manufacturing Excellence," Journal of Cost Management, Summer 1989, 23-31.

TUR91 Turney, "How Activity-Based Costing Helps Reduce Cost," Journal of Cost Management, Winter 1991, 29-35.

ULR90 Ulrich and Fine, "Cost estimation tools to support product design," ASME Manufacturing International, Mar. 1990, 25-28.

WÄS91 Wäscher, "CIM als Basis für ein prozeßorientiertes Gemeinkostenmanagement," Controlling, Mar./Apr. 1991, 68-75.

WED77 Wedekind and Ortner, "Der Aufbau einer Datenbank für die Kostenrechnung," Die Betriebswirtschaft, Apr. 1977, 533-541.

WHI87 Whitney et al., "The strategic approach to product design," Design and Analysis of Integrated Manufacturing Systems (1987), National Academy of Engineering.

WIE90 Wiegmann, "An evaluation of the CMS-PC software as an activity-based cost management tool," Unpublished project report, Spring 1990.

WIR90 Wierda, "Cost Information tools for designers," Dissertation Delft University (Denmark) 1990, Springer Verlag.

WIT84 Wittemann, "Produktionsplanung mit verdichteten Daten," Dissertation Saarbrücken (1984), Springer Verlag.

DIN and VDI guidelines

DIN 4000, "Teilebeschreibung für Teilefamilien," Deutsches Institut für Normung, Beuth Verlag.

DIN 32992 (1), "Ermittlung von Relativkosten-Zahlen," Deutsches Institut für Normung (1987), Beuth Verlag.

DIN 32992 (2), "Kosteninformationen - Verfahren der Kurzkalkulation," Deutsches Institut für Normung (1987), Beuth Verlag.

VDI 2222 (1982), "Erstellung und Anwendung von Konstruktionskatalogen," Verein Deutscher Ingenieure, VDI-Verlag.

VDI 2225, "Konstruktionsmethodik: Technisch-wirtschaftliches Konstruieren," Verein Deutscher Ingenieure (1984), VDI Verlag.

VDI 2235, "Wirtschaftliche Entscheidungen beim Konstruieren," Verein Deutscher Ingenieure (1982), VDI Verlag.

Harvard Business School cases

Camelback Communications (185-179).

Ingersoll (186-189).

John Deere Components Works (187-107/108).

Schrader Bellows (186-272).

Tektronix (188-143).

Appendix A: Glossary

Activity	Virtually all business functions of a company exist to produce products. For every function on any *company hierarchy* level an *activity cost driver* is defined. Every function is included in the product's bill of activities (see *activity consumption*) and, therefore, a function is in this context called an activity.
Activity consumption	Quantity of an *activity cost driver* a product requires for its production.
Activity cost driver	A factor that reflects the cost influencing factor of the respective activity, e.g. hours, units of products, number of setups etc.
Additional costs	Costs considered although no expenses are incurred, e.g. opportunity costs such as rent for using privately owned property.
Batch activity	An activity whose *activity cost driver* is dependent on the number of product batches produced, e.g. any set-up activity or the purchase order activity.
Capacity costs	Costs of an activity that are incurred even if no cost driver is performed, e.g., depreciation, salaries. They are time related costs, i.e., in the short-term they must be considered *fixed* and in the long term *variable*. The *waiting time* varies among activities.
CMS-PC	An activity-based cost management software developed by ICMS, Inc. of Arlington Texas (Tom Pryor, president) in 1989.
Company hierarchy	A hierarchical functional organization allows cost tracing to the hierarchical level at which the costs are caused, i.e., some costs can be traced directly to the lowest level, e.g. depreciation, wages, energy, while other costs can only be traced to higher hierarchical levels, e.g. management costs, salaries.

Design class	Fraction of re-used *products* for a product design alternative based on part values.
Design decision costs	Costs that are *relevant* for the design alternative.
Direct costs	A costing approach in which fixed cost are always left unassigned.
Fixed costs	Fixed and variable costs are time related costs. Fixed costs are those costs that cannot be changed during their*waiting time.*
Main product characteristics (also product cost driver)	Those product characteristics that drive the costs of the product. The characteristics are different for different companies; they depend on the *product family* and, thus, on the *product hierarchy* level.
Method	A program which specifies the search conditions for a particular problem in databases and performs algebra on the retrieved data.
Neutral data storage	A data storage method which does not lose information through any kind of data *proportionalization*, which makes data analyses impossible or biased at least.
Neutral expenses	Expenses are called neutral when they are either not business related or when they are extraordinary, e.g. donations, or currency losses. Neutral expenses are not part of Cost Management considerations.
N_N	The required quantity of an *activity cost driver* when a product is developed and produced anew.
Non-relevant costs	Costs that will appear in the future but were caused in the past are not relevant for a particular decision.
N_R	The required quantity of an *activity cost driver* when a current *product* is re-used.

Operating costs	Costs of an activity that are *variable* with the performed quantity of the respective *activity cost driver.*
Overhead costs	Costs that are allocated to other costs by a *proportionalization* method.
Pre-production activity	An *activity* that is required to put the product in a production status, e.g. research, process planning, or supplier search.
Product	The cost model stores the products in a hierarchical structure. Any item on any hierarchy level is considered a product, i.e., a product in this context can also be a part or a component of another product.
Product cost driver	See *main product characteristics.*
Product cost driver function	A cost function determined by the regression analysis as part of the similarity analysis. The independent variables in this function are the characteristics and the dependent variable is the net present value.
Product family	Products which have the same *main product characteristics* belong to the same product family, while the characteristics differ for products from different families. Products from the same product family also belong to the same *product hierarchy* level, i.e., they can be end-products, components, parts etc.
Product hierarchy	Almost all products have components and parts as subunits which can themselves also be considered products. The cost model stores the products in a hierarchical structure. Only those activities and materials that are actually required for a particular detail level are stored there. The required activities and materials are always recorded on the lowest detail level possible. Information about the use of *products* as parts or components and about their required quantities complete a product description.

Product sustaining activity	An *activity* which enables a company to produce a specific product. The *activity cost driver* of a product sustaining activity is independent from the number of items produced in a particular period.
Production support activity	An *activity* required to actually produce the product and to sustain the product in a producible status, e.g. lathing, engineering change orders, shipping, to record product data.
Proportionalization	The allocation of costs to other cost categories based on a percentage-value.
Reference product	A *product* that is similar to the design product. A reference product belongs to the same *product family* as the design alternative; thus, it has the same *main product characteristics* and is on the same *product hierarchy* level.
Relevant costs	Those costs which are additionally incurred by a company due to a particular decision.
Unit level activity	An activity whose *activity cost driver* is dependent on the number of product units produced.
Variable costs	Costs that vary directly with the *activity cost driver* output.
Waiting period	Number of time periods for which *capacity costs* have to be considered fixed (*fixed costs*).

Appendix B: The SAS-program for the regression analysis

```
OPTIONS LS=72;
TITLE 'SIMILARITY ANALYSIS';
DATA DCC;
INPUT DUMMY X1 X2 X3  Y;
CARDS;
1   15  0.5  0.5  206
2   21  1.0  1.0  272
3   22  0.0  0.5  272
4   17  0.0  0.0  235
5   21  0.0  1.0  302
6   11  0.5  0.5  235
7   10  1.0  1.0  240
8   14  1.0  0.0  208
9   20  0.0  0.0  257
10  16  0.5  1.0  267
RUN;
PROC REG;
MODEL Y=X1 X2 X3;
/ *
```

Vita

Dirk Wiegmann was born on March 17, 1967, in Hamburg, Germany. From 1973 until 1983 he attended first a primary and then a humanistic grammar school in Hamburg. He spent Grade 11 at a boarding school in Southport, Australia, before graduating in 1986 with the Abitur from the Schule Schloß Salem in Baden-Württemberg, Germany.

From 1986 to 1988 Mr. Wiegmann was employed by the Philips Medizin Systeme GmbH, and then until 1989 by the Angermann & Partner International Business Consultants GmbH, both in Hamburg. During those years he also attended the Wirtschaftsakademie Hamburg from which he graduated as a Business Assistant and as a Business Administrator in 1988 and 1989 respectively.

Since 1989 Mr. Wiegmann has been in the graduate program in Industrial and Systems Engineering with a concentration in Manufacturing Systems at Virginia Tech.

Dirk Wiegmann