Diploma Thesis

Life Cycle Management in Manufacturing Process Management

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Statutory Declaration

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Abstract

Over the past two decades, the competitive business environment has increased and it has become crucial for companies to find the most efficient strategy to give them the advantage over the competition. One method of gaining this advantage is to manage and control costs. Life Cycle Costing (LCC) is a tool that helps by analysing the cost of a product during its life span. To increase competitiveness, organisations must optimize not only their products but also all of their processes. Manufacturing Process Management (MPM) does this by addressing the area between product design and production. So MPM also supports the optimisation of the manufacturing area of a factory. The best solution of the manufacturing process can be obtained through the use of different virtual scenarios. It is also possible to reduce time to market and costs while increasing the quality at the same time. The focus of this thesis is to integrate Life Cycle Costing tools and methods with MPM, which is a part of the Product Lifecycle Management (PLM). I will discuss the implementation of Activity Based Costing (ABC) and Case-Based Reasoning methods (CBR) in a PLM tool for an early design decision support.

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1 Introduction

Currently, it is essential for companies to meet customer's needs to ensure that organisations and businesses continue to survive, and are able to stay competitive. For this reason, companies have to focus on the cost and performance of their own products. The right amount of information is required. The time gap of information between the early development phases and the manufacturing phase can be seen in figure 1. Obviously, in the early development phases less technical information is available than later on when the product has been finished. Therefore, in the early development phases, cost estimation methods should be used which do not require as much information as in the end phases, where all information would be available (Ficko, et al., 2005, pp.1327-1329).

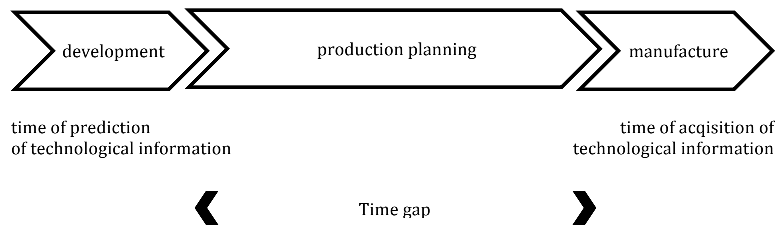

Figure 1: Time gap between times of prediction and acquisition of technological information (Ficko, et al., 2005, p.1329)

It has been shown that in Product Lifecycle Management, early information is necessary to obtain good results. The earlier this information is known, the better the trade-off between the performance of the product and the total cost.

An early economic cost evaluation is, therefore, essential to find the best solution in function of cost and performance (figure1). Usually, the cost per item is the sum of several components and resources (raw material, purchased components, energy, machinery, shop floor, factory). Figure 2 illustrates the efficiency of modification throughout the course of the life cycle of a product. In the life cycle of a product, there is an inverse relationship between the possibility to influence costs and the modification costs. This is shown in the graph with the decrease of the possibility to influence costs while the modification costs increase dramatically. Hence, the best approach would be to decide everything in the conceptual phase without needing to make changes but this is not realistic. Therefore, several approaches have been developed to minimise these additional costs, names analogical, parametric and analytic methods (Duverlie and Castelain, 1999, p.896).

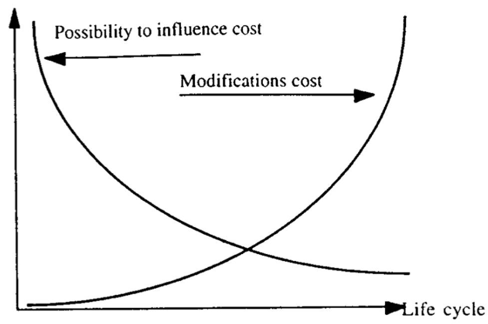

Figure 2: Efficiency of modifications (Duverlie and Castelain, 1999, p.896)

During the design step, around 70% of the costs of a product are determined. That means that the main focus should be on the design step, which is one of the earliest in the Product Life Cycle (PLC). However, to do this at the design step is not easy because many problems occur, for example, not having the necessary data for obtaining the most economic solutions (Duverlie and Castelain, 1999, p.896).
Figure 3 shows the percentage of product costs in different areas. The incurred costs of each area are illustrated along with their impact on the total costs. According to the figure 3, it can be seen that the design phase itself is only 6% of the total costs. These decisions made by 6% will determine 70% of the total costs (Shehab and Abdalla, 2001, p.341).

This description emphasises the importance of early cost estimation approaches, which should influence the decisions in the design step and accurately obtain the end of the product lifecycle costs with the fewest changes (Shehab and Abdalla, 2001, p.341).
The estimation of future production costs is an important topic and it can be seen in several published articles, papers, books and conferences. There are several approaches, which are introduced and discussed in all of these scientific papers and help to improve the economic situation of enterprises.

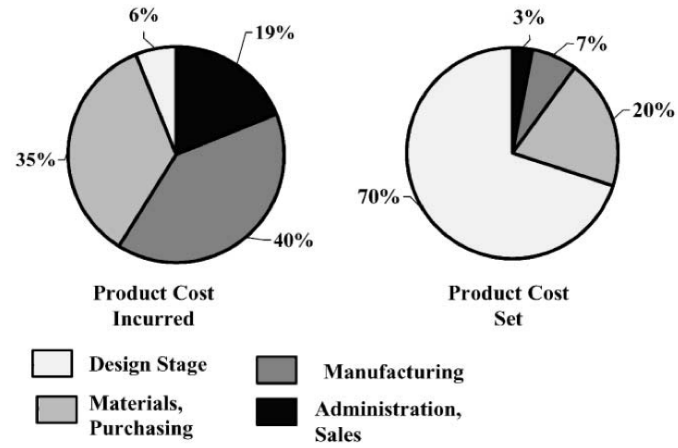

Figure 3: Product costs set and incurred in different phases (Shehab and Abdalla, 2001, p.342)

After the introduction, this thesis approaches the second section which deals with the topic of Manufacturing Process Management and explains the justification of its existence. Furthermore key areas are described where companies could improve their MPM process. Then at the end, the MPM environment will make comprehension of this new PLM-tool possible.

The third section is about Life Cycle Costing and so in order to completely understand it, the life cycle will be explained beforehand. Afterwards, an explanation on the procedure to obtain LCC follows.

With the above-mentioned sections, the thesis sets out to introduce the reader to the contents of section 4. This section provides a new framework for using Life Cycle Costs in Manufacturing Process Management, which has been developed during this thesis. The methodology and the corresponding integration are presented.

Section five describes two cost estimation methods, Activity Based Costing and Case Based Reasoning in detail as they present the main part of the framework.

To summarize all the explanations and the methodology, section six provides a case study, in which the methodology is applied, in order to prove its potential utility within the industry.

Finally, section seven introduces a small possible implementation of the methodology in Windchill, which is an existing MPM software.

To conclude the thesis, future work and a conclusion of LCC in MPM is provided.

1.1 Objectives

The goal of this thesis is to implement Life Cycle Costing in Manufacturing Process Management. This means that a cost estimation approach should be developed in order to be able to calculate costs of a product in the early development stage. After that, the methodology should be applied on a real case and a possible implementation in Windchill should be provided.

1.2 About the Technical University of Compiegne

The University of Technology of Compiegne (UTC) (figure 4) is an institution located in Compiègne (France), which was founded in 1972 by the French engineer Guy Denielou.
With the UTT (based in Troyes), the UTBM (based in Belfort Montbéliard) and UTSEUS in Shanghai, they form the network of the "Universities of Technology".

Figure 4: University of technology of Compiègne (UTC, 2008)

The UTC is a five year school that you can join after passing your A- Level. It offers various engineering specialties, such as mechanical, chemical, biological, computational or civil engineering. It is also a university where you can take a master's or a doctorate with the support of teachers and researchers. As a research centre, there are nine laboratories in the university, each having different specialties.
International experience plays an important part in the politics of this university. Students have many possibilities to go abroad: internships, exchanges with other universities, joint degrees, master thesis etc.
All these characteristics factor in to making the UTC one of the best French engineering schools today, with approximately 4200 students and 650 graduates each year. (UTC, n.d.)

2 Manufacturing Process Management

This section presents an overview of the field Manufacturing Process Management (MPM). It is a part of Product Lifecycle Management and is a business strategy.

2.1 Introduction

Manufacturing Process Management addresses the area between product design and manufacturing, as can be seen in figure 5. Furthermore, a supportive MPM can be used during the production to add, remove, or improve any processes. Figure 5 shows the whole life of a product, except for the last phase (Huet, et al., 2009, p.1).
In an increasingly competitive environment, companies have to optimize not only their products but also all their processes. In order to achieve this goal, MPM facilitates the optimization of the virtual manufacturing area. MPM is a tool/software, which allows the user to simulate the production in a virtual environment. Furthermore, these simulations help to obtain a better manufacturing process while reducing time to market and costs, and also increasing the quality. The main focus is not about what product to produce; it is about how a product is to be produced and how to meet quality, cost and time requirements (Huet, et al., 2009, pp.1-2; Feng, and Song, 2000; Shalvi, 2003, p.14).

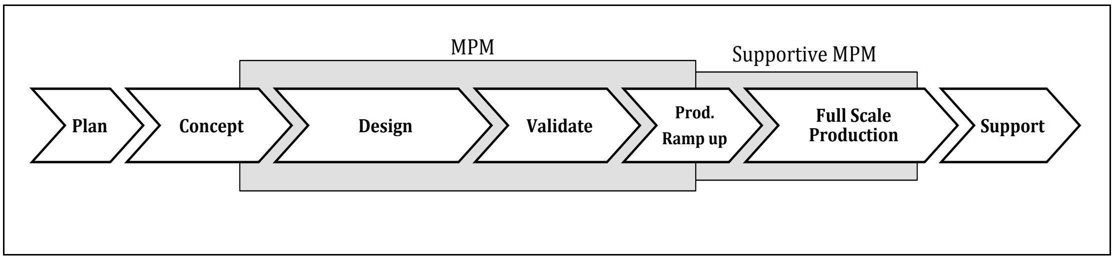

Figure 5: Life Cycle of a product (adapted from Feng and Song, 2000, p.1; Huet, et al., 2009, pp.1-2)

MPM also supports the formal communication between the virtual production and the engineers. It is also possible to work with multi users (Huet, et al., 2009, pp.2-4). The definition of a Manufacturing Engineer is a person in a company who is responsible for the manufacturing areas, processes and also for the use of different methods in an MPM process, such as process planning (Huet, et al., 2009, p.2).

2.2 The importance of Manufacturing Process Management

The following section provides an overview of the relevance of Manufacturing Process Management.

Justification of MPM

One of the major benefits of an MPM system is the possibility to answer “what if” questions. Without making changes in the manufacturing area, it is only necessary to change the virtual environment to improve the efficiency of the virtual company. This is also called a digital factory. The use of this powerful tool enables an engineer to reuse data, redesign, simulate, and manage the development of the manufacturing process. The main advantages of MPM are listed below: (Shalvi, 2003, p.13; Fortin, 2007, p.1)

- Accelerating new product introductions (Shalvi, 2003, p.13)
- Accelerating time to market and time to customer (Shalvi, 2003, p.13)
- Facilitating communication across the enterprise and supply chain (Shalvi, 2003, p.13; Fortin, 2007, p.1)
- Efficiency transferring processes (Shalvi, 2003, p.13)
- Implementing the best practices and reuse of information (Shalvi, 2003, p.13)
- Identifying issues before they become critical problems (Fortin, 2007, p.1)
- Increase visibility of global operations (Fortin, 2007, p.1)

All these benefits show how important it is to use an MPM system and in general, a PLM system to have a successful, competitive company.

Key areas where firms can usually improve their MPM process

The following four points describe the possible improvements for companies in their MPM process.

1. For concurrent manufacturing process planning during the product design. Design engineers pass their design of a certain product to the manufacturing engineers without taking any care, or special required information, for the manufacturing- in other words they throw the

design over the wall (Shalvi, 2003, p.13). However, if the manufacturing engineers could have direct access to the information from the design departments, they could work simultaneously and adapt the manufacturing processes during the design development. The advantage of this is that it reduces time to market and saves money. This information can be used to gain a better-equipped manufacturing area for concurrent production. Figure 6 illustrates this key objective of the Manufacturing Process Management, which aims to make concurrent process and product development possible.

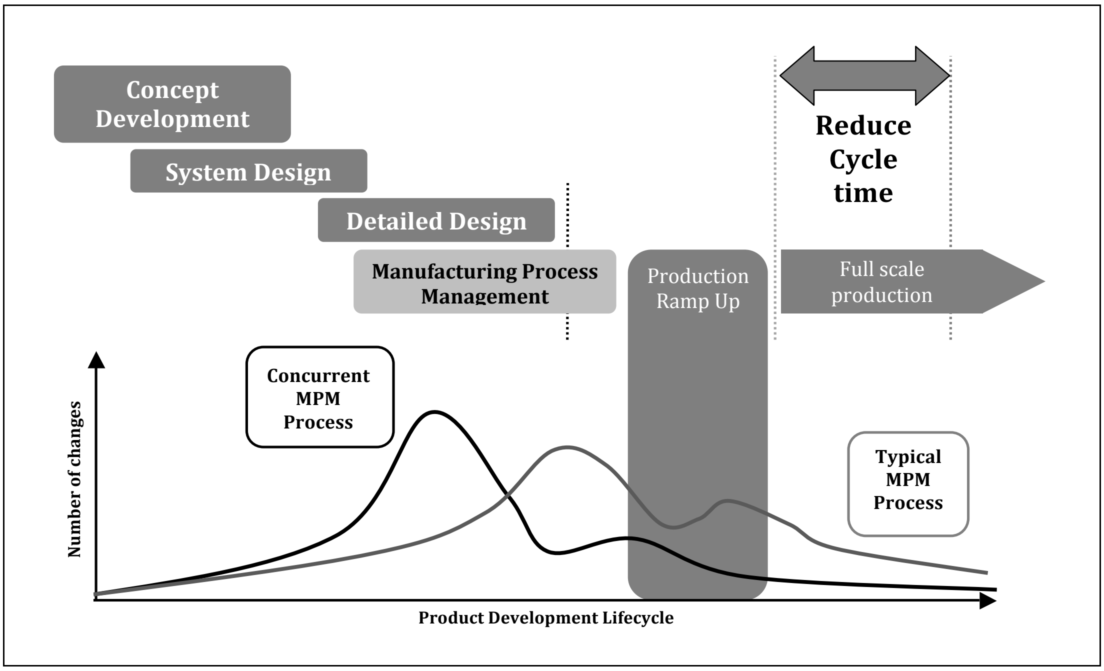

Figure 6: Concurrent Product and Process development (PTC, 2007, p. 2; Shalvi, 2003, p.5)

The timeline in figure 6 depicts the concurrent process and product development and the y-axis is the number of changes. The figure compares the typical MPM process with the concurrent MPM process. The advantage of the parallel development can be seen with the minimization of the cycle time, and an earlier full-scale production, which is a greatly beneficial in a competitive environment. Fortunately, the number of changes occurs earlier and the optimisation of product and process combination can be achieved earlier as well. The number of changes will also decrease compared to the typical MPM process (PTC, 2007, p.2; Ming et al., 2007, p.155).

2. Access to engineering data is provided in a better fashion. In order to create accurate manufacturing processes, the engineering data should be directly reused. The access to parts, classifications, and manufacturing requirements is well provided within MPM software (PTC, 2007, p.2).

3. The elimination of manual processes. Currently, most work introductions are made with Microsoft Word and process plans are created with the help of spreadsheet programs. The use of these manual tools leads to several issues: slower execution of the process, inaccurate data and duplication of data. This can lead to chaos whenever a change occurs (PTC, 2007, p.2).

4. Collaboration within a company will be improved. Since the globalisation of manufacturing companies takes place in different time zones; communication and sharing knowledge between them might be difficult. MPM makes it possible to share knowledge from different places in the world and provides the latest and actual version of all the data (PTC, 2007, p.2; Fortin, 2007, p.3).

Conclusion

This section provided an introduction and illustrates the importance of Manufacturing Process Management. The justification and the areas where companies could improve their MPM process are also discussed. The developed methodology, which will be introduced later on, aims to improve the MPM process or at least to support it by having a proven supporting decision tool, which allows MPM engineers to justify their decisions and helps them to choose the appropriate processes through the factor cost, which will be introduced in section 3.

2.3 The environment of Manufacturing Process Management

MPM is a PLM tool and is placed between Product Data Management (PDM) and Enterprise Resource Planning (ERP) (Figure 7). While these two tools help designers and production engineers manage their work, which is currently well developed, a gap in the process planning still exists (Huet, et al., 2009, pp.1-2; Shalvi, 2003, p.5).

The aim of MPM is to fill this gap and complete the process plan, which is required for manufacturing a certain product. To be able to fulfil their tasks, process-planning engineers need access to specific information, such as available equipment, factory resources, and manufacturing processes, which must be defined by the company. In fact, MPM links two different worlds, the world of production with the world of engineering (Huet, et al., 2009, pp.1-2).

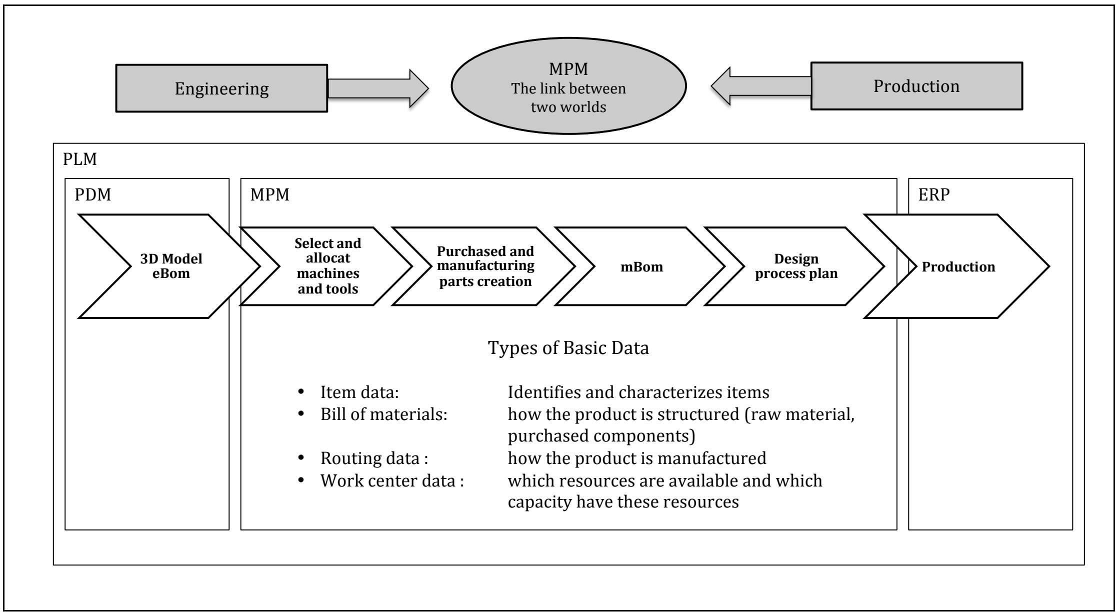

Figure 7: MPM is a PLM tool (adapted from Sly and Schneider, 2011, p.1; Huet, et al., 2009, p.5; Feng and Song, 2000, p.1)

The procedure of MPM

An MPM engineer starts with a 3D CAD model and the corresponding engineering bill of materials (eBOM). The first step is to change the eBOM to the manufacturing bill of materials (mBOM) for another point of view. If a modification takes place on the product design then the update is crucial (Huet, et al., 2009, pp.1-2).

After that, the allocation of all available machines and tools must be done. The right machines, tools and skilled employees have to be selected for the given product. The MPM engineer is also responsible for purchasing parts that cannot be manufactured (Shalvi, 2003, p.6).
After the clarification of the mBOM, the necessary machines, tools, and skilled employees have to be chosen. The end result will be the process plan for the end product (Huet, et al., 2009, pp.1-2).
The outputs of this system are in different areas. The lowest level of these areas, the shop floor, provides work introductions and numerical controlled programs (NC-programmes). For the ERP system, it provides the mBOM, material masters and routings. The basic data is required to fulfil all these steps (figure 7): (Jonsson and Mattsson, 2009, p.66)

- Item data
- Bill of material
- Routing data
- Work center data

These are discussed in more detail in section 4.5.1. With the provided methodology in this master thesis, the Life Cycle Costs of a product will be an additional output, which will provide more improved parts for the product in MPM.

2.3.1 Product Data Management (PDM)

As can be seen in figure 7, the necessary information for the MPM tool is available from the PDM tool. PDM is a tool which controls and tracks data for a specific product. Usually, the tracked information contains technical specifications of the items, types of material, and specifications for the manufacturing process (data that is required for producing the product). All the information that is created by the engineers from the designing (CAD) and calculating (FEM) of a product is stored in a database. The MPM tool makes use of this information to define all the processes for a certain item. It also holds information about the product structure and engineering bill of materials (eBOM) (Huet, et al., 2009, p.4; Shalvi, 2003, pp.5-7).

Bill of material (BOM)

BOM is a list of components, raw materials, subassemblies, parts, and the necessary quantities needed to manufacture an end product. EBOM is a well-structured bill (list) of components that are required for the final end product; it is the view of the designer. On the other hand, the mBOM illustrates a structured list of components, which are used to make the end product. This is the view from the manufacturing side. The structure correlates to the manufacturing processes or assembly steps *Introduction to WindchillMPMLink 9.1* (Anon., 2009, p.2-5).

For example, the shown product structure in figure 8 illustrates the progress of these product structures. The figure shows the breakdown of a pen, which consists of a body, a cap, and a cartridge. Furthermore the body can be divided into a barrel, a tip, and a top. This is a typical “explosion” of the design *Introduction to WindchillMPMLink 9.1* (Anon., 2009, p.2-5).

The CAD structure is identical to the eBOM, just a small documentation file is added. Only the mBOM is different. Differences include listing just the parts needed and not the quantity. Also, it summarizes the assembly required, such as giving details about the phantom assembly, meaning the distinction of assembling the upper and lower body separately. This is an assembly that only exists in the eBOM to mBOM transformation and is shown in the downstream view (Shalvi, 2003, p.18).

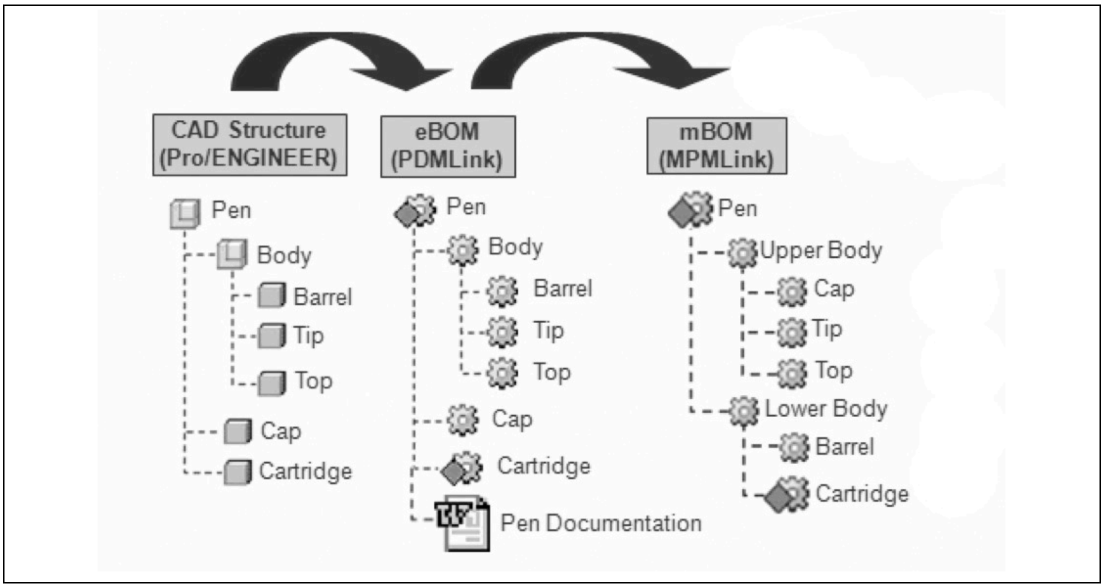

Figure 8: Difference between eBOM and mBOM *Introduction to WindchillMPMLink 9.1* (Anon., 2009, p.2-5)

This breakdown is needed so that these parts can be assembled at different workstations. The mBOM shows details about the upper body and the lower body, which are assembled separately before they are joined together to make the final product (Sly and Schneider, 2011, p.2).

It is important to note that the **Bill of activities** (BOA) is something different. It corresponds to chapter 7.3.2, where Activity Based Costing is placed and lists all activities required to produce one product (Emblemsvåg, 2003, p.130).

2.3.2 Enterprise Resource Planning (ERP)

ERP requires the information from MPM for production scheduling but this does not mean that MPM replaces master resource planning. ERP is an information platform that is often used in manufacturing enterprises. This technology used a database to integrate and control all information related to the product, customer, employee, financial data and supplier. The path from the ERP system to the MPM is the process plan definition and the mBOM (Slack et al. 2009, p.411; Ming et al., 2007, p.155).

2.3.3 Product Life Cycle Management (PLM)

PLM is a method that integrates several data management techniques into one tool to organize all the data around a product regarding its entire life. Currently, PLM solutions include CAD/CAx/PDM and MPM. Future PLM solutions will also deal with digital sketches and material requirement planning (MRP). Furthermore, PLM does not simply provide support for the future product but also manages the product throughout its whole life.
Figure 9 shows the important role of MPM in a PLM framework. Huet, et al. (2009) believe that the MPM system is the heart of the framework. The proposed PLM paradigm (figure 9) integrates computer tools along three axes and shows MPM in the middle of these three axes. The axes are listed below (Huet, et al., 2009, p.2):

- The concept to product axis
- The engineering to production axis
- The supplier to client axis

The concept to product axis

This axis includes all the activities that are necessary to develop a new product. It focuses on the physical representation of the product. In the virtual environment, engineers make use of CAx software to put their ideas to real solutions (Huet, et al., 2009, p.2).

The engineering to production axis

This axis includes the internal process for product manufacturing. The focus is on the product development processes. The responsibility is to manage the data from the PDM system to the MPM and afterwards, into the ERP system, as can also be seen in figure 9 (Huet, et al., 2009, p.2).

The supplier to client axis

The main focus of this axis is the external company processes. The managing of the expanded supply chain is the challenge that should be solved here. It starts by making the decisions, and then chooses which supplier will be selected. This finally ends with which products can be sold to the clients. One of the major roles linked to this axis is logistics (Huet, et al., 2009, p.2).

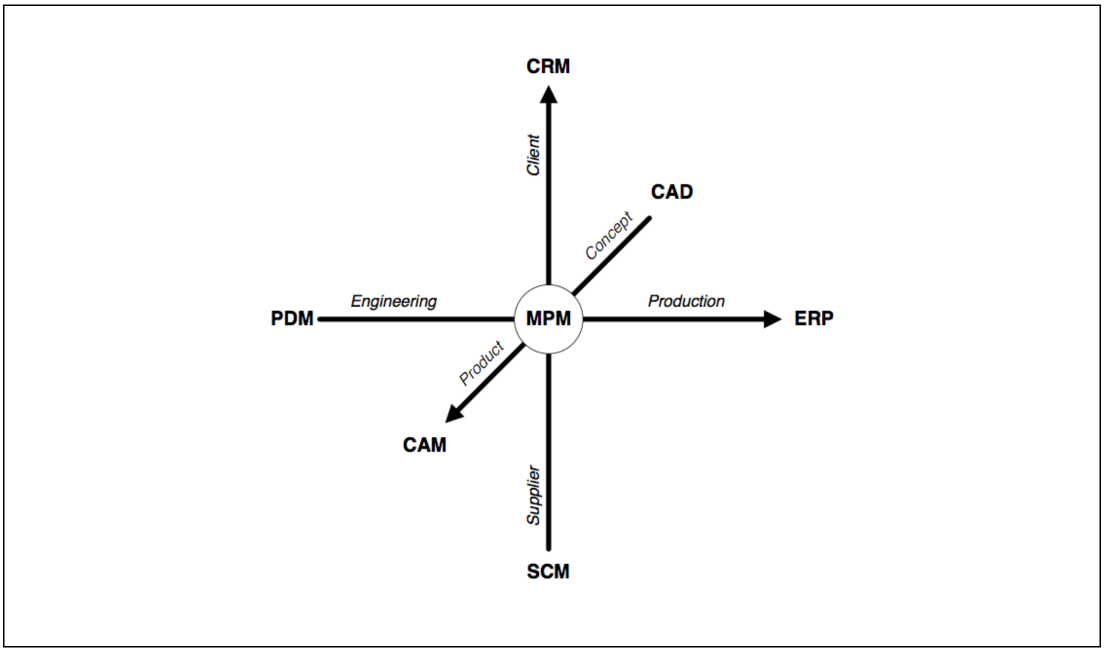

Figure 9: Computer tools that Product Lifecycle Management systems seek to integrate (Huet, et al., 2009, p.3)

Conclusion

This section shows where MPM is placed in a PLM tool. Advantages of MPM are also described. Moreover Huet (2009) believes that MPM is the heart of a PLM tool (figure 9). This leads into the introduction of Life Cycle Costing in MPM, through which the factor cost can help make the right decisions. LCC is discussed in the following section, so that one may have knowledge about all the participating methods.

3 Life Cycle Costing

Before being able to elaborate about Life Cycle Costing, it is necessary to clarify the basic concepts, which are included in the following section.

3.1 Fundamentals of Life Cycle Costing

The fundamental concept behind Life Cycle Costing is the life cycle. This will be discussed in the following paragraph, in order to facilitate complete understanding of the Life Cycle Costing approach. After this the Life Cycle Costing procedure is provided.

3.1.1 The Life Cycle

The life cycle theory has been in use since the 1970's (Ryan and Riggs, 1997, p.33). To put it simply, the life cycle describes the process from the beginning to the end, i.e. a production life cycle will start with the first conception of the product and will end with the logistic. Here is a list of the several points of view that a life cycle can be seen from: (Emblemsvåg, 2003, p.16)

- Marketing perspective
- Production perspective
- Customer perspective
- Society perspective

Marketing perspective:
The marketing perspective is the necessary background knowledge for the market life cycle. This life cycle concept is designed as a process of products or services from market development to market decline. A marketing executive will predominantly think in terms of marketing perspective but other perspectives will also taken into consideration. The marketing perspective can be divided into at least four distinct areas (figure 10) (Emblemsvåg, 2003, p.16).

- Introduction
- Growth
- Maturity
- Decline

Figure 10 shows an example of the relationship between sold products and the stages of the product life. In the introduction stage, the sales are generally very low and the innovation factor of the product is usually very high, with very few or no competitors within the market. In contrast to this, the maturity stage is where the sales tend to be maximized as the product has reached mass marketed standards and the number of competitors becomes stabilized. The next stage of this approach is called decline. This is when the sales start to decrease. Companies should start thinking about discontinuing as soon as they have found an alternative product, which will yield higher profitability (Emblemsvåg, 2003, p.22).

However, one of the biggest issues is that companies tend to keep their products out too long. In other words the companies ignore the warnings from the industry and continue to make the products at the same large scale in order to try to maintain the same level of success as before. This is analogy to an ostrich, which sticks his head in the sand when danger comes near. The ostrich (firm) believes that nothing can happen by what he cannot see, while the hungry lion (competitors) sees only a easy meal.(Ryan and Riggs 1997, pp.33-34)

In reality, the illustrated shape of the curve will not occur. This figure shows only a theoretical shape of the marketing life cycle (Emblemsvåg, 2003, p.22).

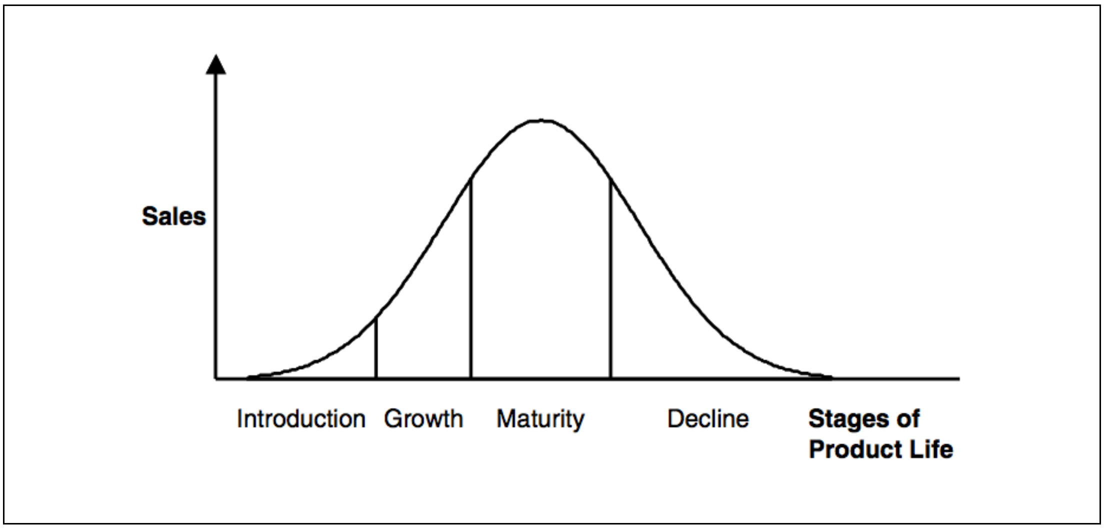

Figure 10: Market life cycle (Emblemsvåg, 2003, p.22)

Production Perspective:

The production perspective, on the other hand deals with the manufacturer's point of few, which consists of five main stages of processes: (Emblemsvåg, 2003, p.16)

- Product conception
- Design
- Product and process development
- Production
- Logistics

This view only focuses on how to produce a product, starting with the conceptual idea of it. Also, the designing step follows the development of the processes that enable manufacturing of it. The last steps of this view focus directly on production and delivery afterwards (Ryan and Riggs 1997, p.37).

Customer perspective:

The customer perspective starts when the product has been released to the public. This perspective is made up of five steps (figure 11) (Emblemsvåg, 2003, p.17):

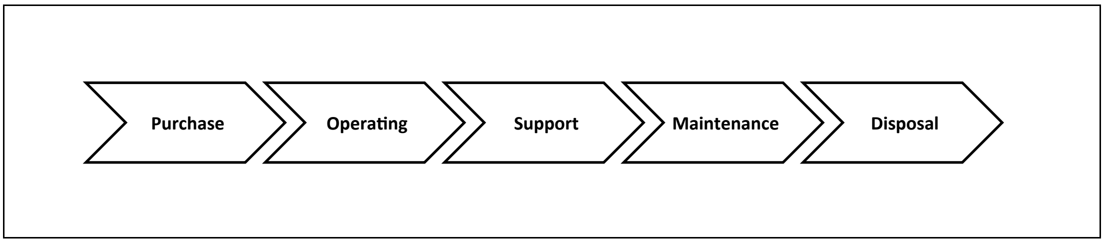

Figure 11: Customer perspective (Emblemsvåg, 2003, p.17; Stauss et al., 2006, pp.207)

As mentioned before, the customer perspective starts with purchasing. The price (which amount of money the customer has to pay) is created by the production plus an add-on (profit). The customer perspective has a high relevance because it will most likely be the most complete one. To keep that in mind is of paramount importance in order to generate competitive advantages from this knowledge as Toyota did (Emblemsvåg, 2003, pp.16-17; Stauss et al., 2006, pp.207-208; Ryan and Riggs 1997, p.37).

Toyota is one company, which tries over years to minimize their total life cycle costs. Toyota's customers profit from this strategies because their cars are virtually problem free after purchasing. For that reason they can charge a higher price than their competitors and simultaneously the profit increases. It is a win-win situation, because both customer and manufacturer benefit. The customers know that they save money and hassles.(Emblemsvåg, 2003, pp.16-17)

Society perspective:
In order to connect all the different perspectives, it is necessary to introduce one more, the society perspective. This perspective entails costs that are imposed on the company by external factors that do not come from market stipulations. Rather, these costs come from societal stipulations imposed on the company because of moral grounds. Furthermore, this perspective is made up of two different activities: (Emblemsvåg, 2003, p.17)

- Disposal
- Externalities

Currently, the world's focus is increasingly on environmental issues safety and protection of the environment. The topics of sustainability and renewability are, indeed, discussed in great detail. Due to this, companies cannot escape from their responsibility to produce environmentally friendly products that can be easily reused or disposed. The current trend is that disposal costs are becoming the costs of the manufacturer or of the user (Kang and Brissaud, 2007, p.469).

To be able to allocate all of these costs, the most comprehensive perspective is the view at the product; figure 12 depicts the concept of product life cycle. This is based on one unit, which in contrast to the marketing perspective, is based on several units (Emblemsvåg, 2003, p.18).

3.1.2 Product Life Cycle

There are several definitions of the product life cycle, but Emblemsvag's definition is, in my opinion, by far the most complete. The PLC is built with processes or activities.
Everything starts with the needs of the customer. If there are no customers, then there are not any needs. The customer needs can be found between the activities "Mining" and "Material processing" (Kang and Brissaud, 2007, p.468).

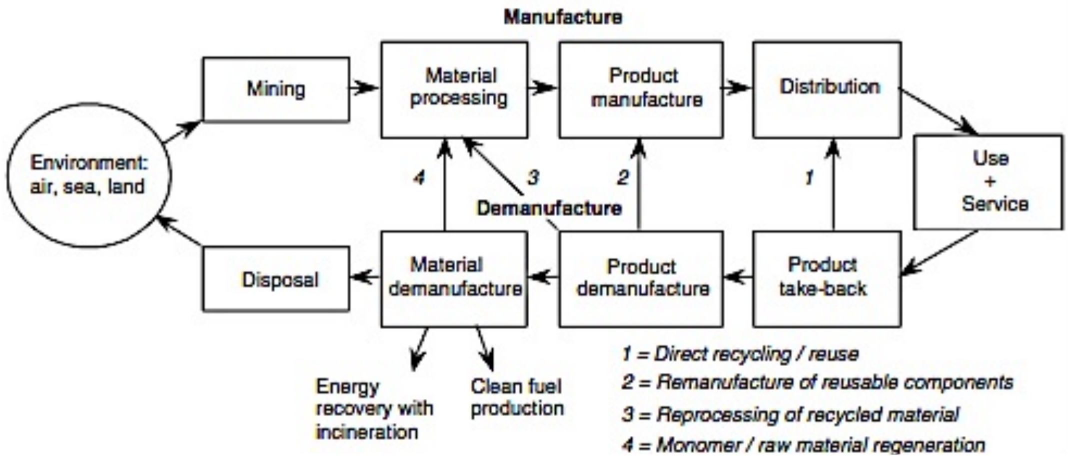

Figure 12: Generic representation of a PLC (Emblemsvåg, 2003, p.18)

The PLC is a closed loop, which means everything starts where it ends, i.e. the environment. In the upper part of the PLC, is the manufacturing area, where Manufacturing Process Management is placed and on the opposite side of this area is the End of Life phase (EOL). In this picture, the area is called the demanufacturing area. Correspondingly, the customer is placed between the manufacturing area and the demanufacturing area. The customer is the one who is using the product and can be seen on the right (use+service). On the top flow, the customer is the key factor, so the main aim comes from customer needs to customer satisfaction (Emblemsvåg, 2003, p.19; Kang and Brissaud, 2007, p.46).

3.2 Life cycle Costing

After the clarification of the life cycle, the next step to the top is the clarification of the Life Cycle Costing (LCC) approach. As with most approaches, LCC has continuously been improved upon over time. Basically, it was developed by the US Department of Defence (DoD) in the early 1960s to increase the effectiveness of government procurement (Kang and Brissaud, 2007, p.468). At the beginning of the product development, it was soon realized that it is better to eliminate costs before they occur instead of waiting and cutting afterwards. Due to this, LCC is closely related to the design and development phases. This shows a shift from cutting the costs to control costs during the design phase. Indeed, the Institute of Defence

Analyses (IDA) has explored the fact that more than 70% of the costs for a weapon system during its entire life occur during the development and design steps. In any case, to cut the costs after they are incurred is ineffective, which is currently the traditional approach (Emblemsvåg, 2003, pp.30-31).
Quite a few definitions about LCC can be found in several pieces of work. Some of the better ones are mentioned below:

"The total costs that are incurred, or may be incurred,
in all stages of the product life cycle."
(Emblemsvåg, 2003, p.29)

"The total cost throughout its (an asset's) life, including
planning, design, acquisition and support costs, and any other
costs directly attributable to owing or using the asset."
Government Asset Management (Anon., 2001,
cited in Emblemsvåg, 2003, p.27)

"The life cycle cost of an item is the sum of all funds
expended in support of the item from its conception and
fabrication through its operation to the end of its useful life"
(Woodward, 1997, p.336)

"The amortized annual cost of a product, including capital costs,
installation costs, operating costs, maintenance costs,
and disposal costs discounted over the lifetime of a product."
(Clinton, 1993, p.4)

"The sum total of the direct, indirect, recurring, nonrecurring, and
other related costs incurred, or estimated to be incurred,
in the design, development, production, operation, maintenance,
and support of a major system over its anticipated useful life span."
OMB Ciricular A-109 Major System Acquisition (Anon., 1976, p.3)

For this master thesis, I decided to follow Woodward's definition (1997), as I find that it fits the best. LCC in MPM is an undeveloped topic, which addresses the virtual areas of a manufacturing process by implementing the factor cost.

Purpose of the Life Cycle costing approach

After clarifying the Life Cycle and the Life Cycle Costing, the purpose of LCC follows (Emblemsvåg, 2003, p.24):

1. LCC was originally developed for utilization as a tool to aid decision making, so that companies will be sure to make the right decision. LCC also makes for an effective engineering tool, which helps with design, procurement, and infrastructure decisions (Emblemsvåg, 2003, p.24).
2. Since LCC provides help in areas where traditional cost accounting is not sufficient; it offers valuable cost insights for cost accounting and management as a result (Emblemsvåg, 2003, p.24).
3. From an environmental standpoint, LCC has become a useful design and engineering tool (Kang and Brissaud, 2007, p.469).

3.3 Life Cycle Costing Procedure

After the definitions and the purposes of Life Cycle costing, which were previously provided, the general procedure of LCC is depicted in figure 13. Harvey (1976, pp.343-347) published an extensive review of LCC techniques in 1976.

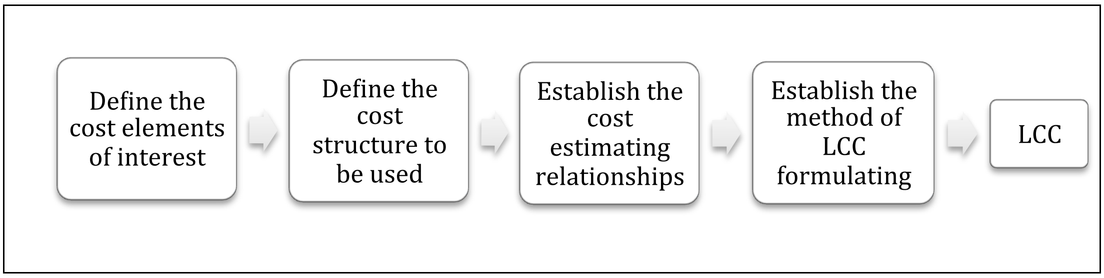

Figure 13: Harvey's LCC procedure (Woodward, 1997, p.336)

His basic procedure includes four steps. If all these steps are clarified, then the LCC framework is determined (Woodward, 1997, p.336).

3.3.1 Define the cost elements of interest

The elements of interest are all of these cash flows, which occur during the entire life of the product. From the definition of LCC mentioned before, it will include all the expenses from the acquisition to the final disposal at the end of its useful life.

In order to achieve good results, all costs should be included, but the opinions vary in terms of the precise identification (Kang and Brissaud, 2007, p.468). The secret to efficient cost estimation is to be as broad as possible but at the same time include all the necessary details (Woodward, 1997, p.336).

3.3.2 Define the cost structure to be used

The second step of Harvey's LCC procedure is to define the cost structure. Literature emphasises that cost elements are grouped and afterwards the cost structure is assigned according to the different phases of the Product Life Cycle. Ultimately, the cost structure depends on the required depth of the LCC study (Woodward, 1997, p.336). Furthermore, the level of breakdown is also dependent on the kind of information and data that is available (Kang and Brissaud, 2007, p.468).

Plenty of different cost structures can be found (Woodward, 1997, p.336). White and Oswald (1976, pp.39-42) proposed one structure, which deals with three different cost categories, which is illustrated in figure 14. It illustrates the three stages.

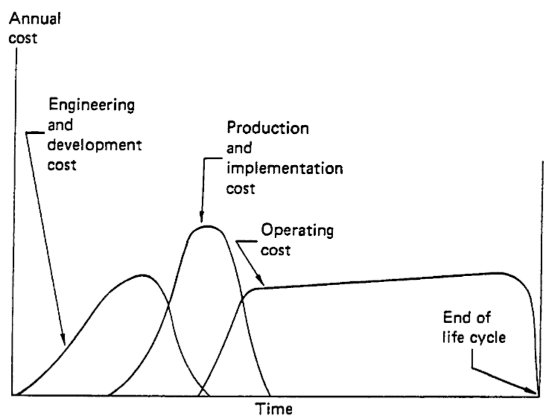

Figure 14: One example of cost categorisation (stages of life cycle costs) (Woodward, 1997, p. 336)

Finally, Harvey states that an important point is well-structured costs break down. The structure has to be designed in a way that the analyst can perform the LCC analysis. (Harvey, 1976 cited in Woodward, 1997, p.336)
One example of a breakdown of the grouped stages is illustrated in figure 15.

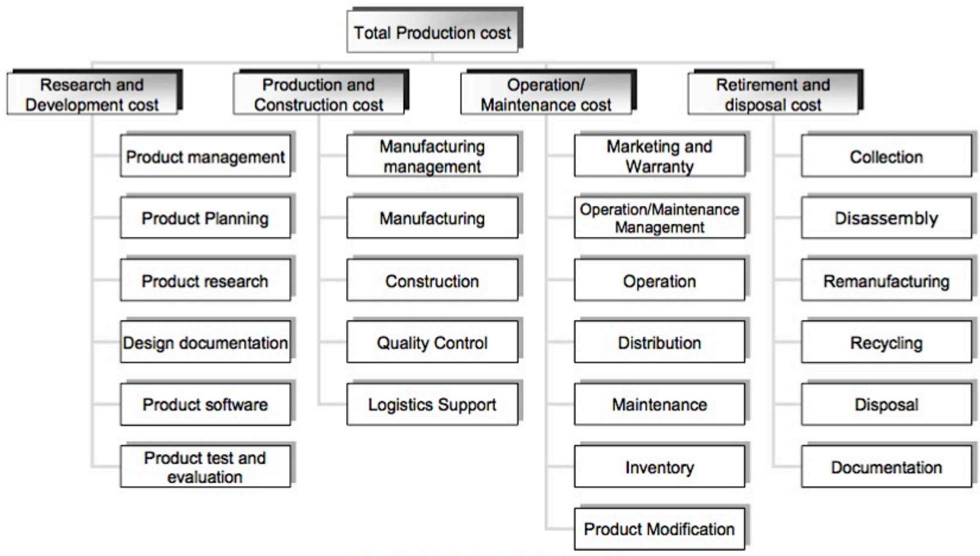

Figure 15: Cost breakdown structure (Kang and Brissaud, 2007, p.469)

3.3.3 Establish the cost estimating relationships

Once the two previous steps are complete, the right cost estimation approach needs to be chosen. Good cost estimation is essential for an enterprise because it has a direct influence on the effectiveness and performance of their business. It is imperative that over-estimation and under-estimation are avoided as much as possible. If the company underestimates their costs, it could lead to financial losses. Overestimation might, on the other hand result in loss of business and goodwill in the market (Kang and Brissaud, 2007, p.468).
Literature about cost estimation covers an extensive variety of issues. Cost estimation starts in the manufacturing area from highly customized and specific products to completely standardised and general products, from process cost optimisation to specific techniques for allocating and assigning overhead costs. Then there is, finally, several cost estimation approaches

that range from classic costing to highly developed cost estimations. Niazi categorized Product Cost Estimation Techniques (PCE) into quantitative and qualitative ones (Niazi, et al., 2006, pp.563-564).

Qualitative Cost Estimation Techniques are mainly based on a comparison analysis of a new product with previous products, which have been already manufactured - (as a result their price is well known). The aim is to identify the similarities that these two products share. With the identification of the similarities, the cost estimation does not need to be started from scratch; the past data will be transferred over to the new product. In this sense, the past information, or previous experience, can be of great help in developing a new product that is similar to the old one. Obviously, it is necessary to know all the data from the previous product. Niazi mentioned in his paper that the qualitative cost estimation techniques in general help to obtain rough calculations during the design step (Niazi, et al., 2006, pp.563-564; Kang and Brissaud, 2007, p.468).

The Quantitative Cost Estimation Techniques are based on detailed analyses of each step of the production. This analysis includes all features and is very thorough. Unfortunately, this technique is very costly and time consuming because it does not simply take past data, or previous knowledge to estimate new product costs. This technique is, however, known for more accurate results, which is the reason why it is more time consuming (Cavalieri, 2004, p.168; Kang and Brissaud, 2007, p.469; Niazi, et al., 2006, pp.563-564).
The classification of cost estimation approaches is illustrated in figure 16.

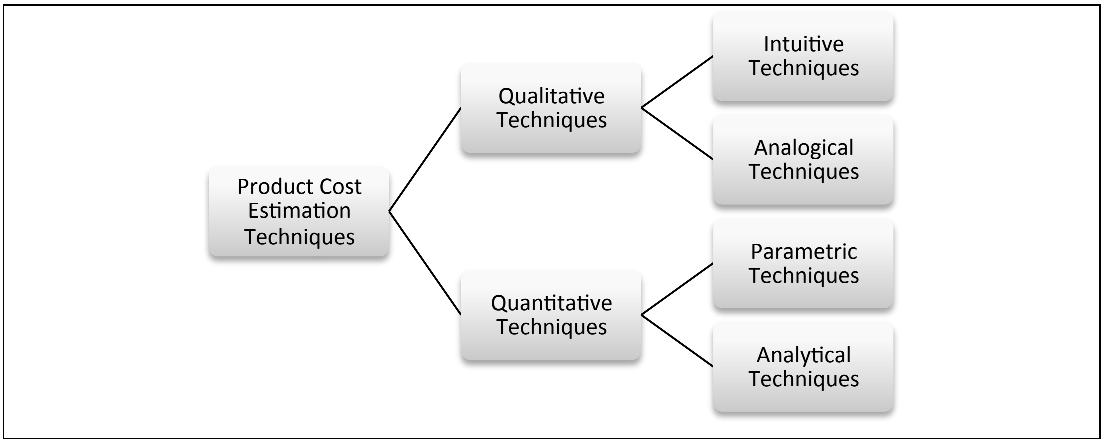

Figure 16: Initial classification of the PCE techniques (Niazi, et al., 2006, p.564)

The quantitative techniques can be divided into Parametric and Analytical techniques and the qualitative techniques into Intuitive and Analogical techniques, which are proposed on the next pages, marked with A, B, C and D. Niazi introduced an extensive hierarchical classification of these cost estimation techniques in his paper (Kang and Brissaud, 2007, p.468). Figure 17 illustrates all the different kinds of cost estimation approaches according to their detailed models.

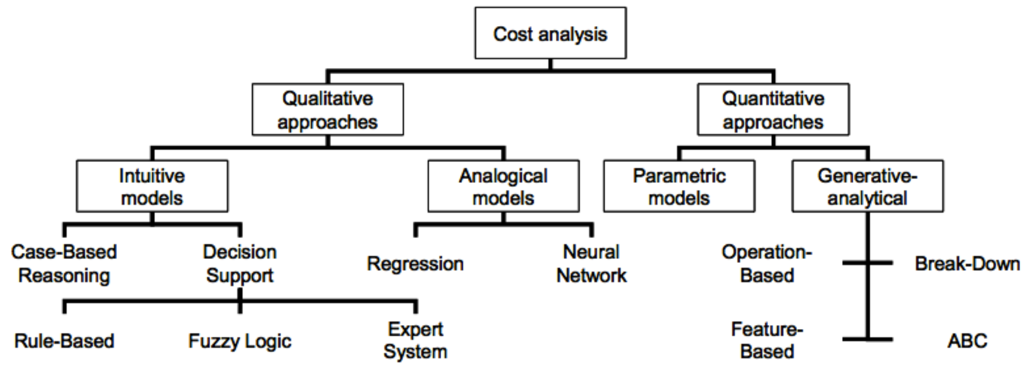

Figure 17: Classification of cost estimations approaches (Niazi, et al., 2006, p.567)

A. Intuitive Cost estimation Techniques

The intuitive cost estimation approaches work by utilizing past experience. A domain expert's knowledge is used to perform cost estimations for assemblies and parts. The knowledge can be stored in the form of decision trees, rules, or judgement, etc. A database is useful for being able to have a good overview of all stored data. This database helps the end user to improve his cost estimation and decision-making processes. In fact, the result depends predominantly on the estimator's knowledge (Niazi, et al., 2006, p.564; Kang and Brissaud, 2007, pp.468-469).

Two major difficulties occur with these techniques. The first one is the degree of similarity - how to measure it and how to compare it. The second one is how to integrate the technological progress over the years (Cavalieri, 2004, p.168).

Niazi et al (2006) proposed three different subcategories under intuitive techniques, which are discussed below.

- **Case Based Methodology** – this cost estimation approach is also known as Case Based Reasoning (CBR). This approach makes use of previously obtained information from a database. The database collects all the information from solved design cases by adapting past solutions to the new problem. If the characteristics are well matched, then the previous case will be chosen to adapt for the new one. This often requires changes to assemblies and parts. After the success of a complete adaption, the newly obtained design is stored in the database (Watson, 1997, p.20). One of the greatest benefits, which this technique possesses, is that through combining past solutions with future products, it is possible to reduce the need for designing from scratch. Niazi mentioned that this approach is useful to estimate costs in the conceptual design stage. The support from the past cost estimations avoids unnecessary calculation. In fact, this approach minimizes the cost estimation time. However, this technique is only useful if similar past cases exist (Niazi, et al., 2006, p.564).

- **Decision Support Systems (DSS)** - these approaches are used in evaluating design alternatives. The main point of these approaches is to assist estimators with their decisions, or to help in making better judgements in different estimation levels, by using experts' stored knowledge. To integrate expert knowledge, the artificial intelligence (AI) philosophy is used in a way, which facilitates problem solving and helps as a decision-aid tool. In this context, it may illustrate, for example, a segment of the system, including information about product characteristics, machining processes and manufacturability analysis. At least three different systems exist (Cavalieri, 2004, p.169; Niazi, et al., 2006, p.564).

    - Rule-Based Systems are based on cost calculation and process time.
    - Fuzzy-Logic Approaches is a helpful cost estimation approach in handling uncertainty. It works with rules, which are applied to get more trustworthy estimates.
    - Expert Systems store the obtained knowledge in a database to enable a more consistent, quick, and accurate result.

B. Analogical Techniques

These techniques use similar criteria, based on previous cost data for products, whole costs are already known - such as Back-Propagation and Regression Analysis Models (Kang and Brissaud, 2007, p.469).

- **Back-Propagation Neural-Network (BPNN) Models** make use of a Neural Network (NN). The NN can store individual knowledge and can be trained to find answers to questions with inferences, even if it did not know the answer before. Consequently, these approaches are useful for uncertain requirements. It can be used for solving non-linear problems as well (Niazi, et al., 2006, p.566).

- **Regression Analysis Models** forecast the costs of a new product by using a linear relationship between historical cost data of the past design cases and the value of certain selected variables from the future product. Hundal and Poli (1988) adopted the regression methodology based on a similar principle. They assumed linear relationships between the cost factors and the final product (Kang and Brissaud, 2007, p.469; Niazi, et al., 2006, p.566).

C. Parametric Techniques

Parametric techniques attempt to evaluate the total costs of a product by applying different cost parameters. These Cost parameters characterise a product but they don't describe it completely, such as the volume, the number of input-outputs, and the mass (Duverlie and Castelain, 1999, p.896; Kang and Brissaud, 2007, p.469). These methodologies can be successfully used in particular situations where the parameters can be easily identified. The main area is the quantification of unit costs of a certain product (Niazi, et al., 2006, p.567). The major disadvantage of these techniques is that they assume a linear relation between the value of the specific parameters and the costs (Duverlie and Castelain, 1999, p.896).

Cavalieri proposed a cost estimation approach based on parametric techniques, which allows for the calculation of unit manufacturing costs of a given disc brake. They developed three parameters in their model: number of cores which are needed in the cast iron process, unit costs of raw material, and the weight of the raw disk. These are expressed in the following equation (Niazi, et al., 2006, p.567).

Equation 1: Unit costs of one finished disk brake (Duverlie and Castelain, 1999, p.896)

$$C = FC + \left(C_{CO}N_{CO} + \frac{C_{rm}TF}{1 - SC}\right)W$$

C	is the unit costs of one finished disk brake,
FC	is the fixed costs that occur in the production,
C_{co}	the core costs per kilogram of cast iron
N_{co}	number of needed cores
C_{rm}	the unit costs of raw material
TF	cast iron steel conversion factor
W	weight

In this case, more than one parameter is chosen because if there was only one variation between them, the data would be too large. However, the mentioned model solves this problem by using more than one parameter. The evaluation of the model shows the superiority of the proposed approach compared to the linear regression model (Cavalerie, et al., 2004 cited in Niazi, et al., 2006, p.567).

D. Analytical Techniques

These methods work with the cost estimation from the product base. The product is divided into several details such as units, activities, and operation; and the costs will be determined from each elementary consumed resource during the production. The final product costs will be expressed as a summation of all the disassembled elements. These methodologies can be classified into five different categories, such as operation based approach, breakdown approach, tolerance based cost approach, and the feature based cost estimation which are described below (Kang and Brissaud, 2007, p.469; Niazi, et al., 2006, p.568; Partha and Rajkumar, 2010, p.146)

- The **Operation Based Approach Method** requires a special type of information, which is primarily available in the final design stages. To estimate the total costs of the manufacturing process, this technique links the costs associated with the time to perform the manufacturing operations, set-up time, and non-productive time. A summation of all these factors results in the total costs of the manufacturing process.

The cost model, developed by Jung, includes three different times: operation time, non-productive time, and set-up time. This approach is used to optimise the machining costs by comparing different manufacturing operations. The formulation is illustrated bellow (Jung, 2002 cited in Niazi, et al., 2006, p.567).

Equation 2: Total costs oft he operation based approach (Jung, 2002 cited in Niazi, et al., 2006, p.567)

$$Mfg\ cost = (R_0 + R_m)\left[\frac{T_{su}}{Q}T_{ot} + T_{no}\right] + material\ costs + factory\ expenses$$

R_0 Operators Rate
R_m Machining rate
T_{su} setup time
Q batch size
T_ot operation time
T_{no} nonoperation time

It is not possible to use this model to evaluate design alternatives because of the required information, which is only available in the final stage of the design cycle (Cavalerie, et al., 2004, p.147).

- The **Breakdown Approach** calculates the total product costs by adding together all the costs that occurred in the production cycle and it takes into consideration the material and overhead costs. Detailed information from the consumed resources is needed to obtain a suitable result. The consumed resources are the necessary items needed to produce the product; it includes maintenance, processing and purchasing details (Duverlie and Castelain, 1999, p.896; Kang and Brissaud, 2007, p.469). The cost model proposed by Son considers seven factors, such as machining, computer software, labour, setup, material, and tooling costs. The following equation represents the machining costs C_m. The requirement of such detailed factors means that the use of this technique is only possible at the end of the design phase (Son, 1991 cited in Niazi, et al., 2006, p.568).

Equation 3: Machining costs of the breakdown approach (Son, 1991 cited in Niazi, et al., 2006, p.568)

$$C_m = (utility\ cost) + (maintenance\ cost) + (repair\ cost) + (insurance\ cost) + (property\ cost)$$

$$C_m = \sum C_u T_m + C_{mt} T_{mt} + C_r T_r + \alpha F_k + b F_k$$

C_u	utility cost per unit time
T_m	the machining time
C_{mt}	the maintenance cost per unit time
T_{mt}	the total maintenance time
C_r	the repair cost per unit time
T_r	the total repair time
α	the insurance premium
F_k	the initial investment
b	property tax

- The main aim of the **Tolerance Based Cost Models** is to estimate the costs of a product with the help of design tolerances, which are a function of a specific product (Niazi, et al., 2006, p.568).

- The objective of the **Feature-Based Cost Estimation Model** is to estimate product costs with the identification of features, which are related to costs. Furthermore, the costs of the features will be determined. In order to achieve appropriate costs, two other features are mentioned in the literature. The first one is process oriented, such as casting, injection molding, or machining. The second one is design related, such as material or geometric detail. This technique allows calculating the cost for a product from particular features. However, the methodology has limitations. The three major limitations are mentioned below: (Duverlie and Castelain, 1999, p.896; , p.469; Niazi, et al., 2006, p.568)
  - Complex parts
  - Very small geometric features
  - The use of machining processes

- **Activity Based Costing (ABC)** The main aim of Activity Based Costing is to calculate activity costs. The product cost estimation is the secondary operation. In this context, the costs of a product are the summation of all the costs of all the activities that take place to manufacture that product. Therefore, after determining the activities, the consumption of resources for each activity has to be determined (Özbayrak, 2004, pp.49-50; Partha and Rajkumar, 2010, p.146). Cooper and Kaplan introduced this method. They mentioned, that ABC accurately distributes the overhead costs, which have arisen from manufacturing a product. Furthermore, it highlights all the inefficient and wasteful areas; meaning all the activities that do not add any value to the product. The basic idea of the ABC approach in product costing is provided in the following equation (Gunasekaran and Sarhadi,1998, p.232):

Equation 4: Activity Based Costing (Gunasekaran and Sarhadi,1998, p.232)

$$Total\ costs\ of\ a\ product = raw\ material + \sum all\ value\ adding\ activities$$

A disadvantage of the ABC procedure is that it is time consuming and the implementation is expensive. It is used anyway because the cost estimation results are the most accurate (Partha and Rajkumar, 2010, p.146).

Of the four different methods, no one in particular is the most suitable for all of the stages of the development cycle. Deciding upon which of the different methods to use depends on the area and the requirements (Ficko, et al., 2005, p.1329).

Figure 18 illustrates a comparison of different cost estimation methods, with their advantages and limitations in practical use for the completion.

Cost estimation technique	Advantage	Limitations
Parametric	Rapidity of execution	Parameters not included can become important
	Repeatable and objective	Useful in combination with other methods
	Less information required than analytic methods	CERs are too simplistic to predict costs
	Good for budgetary estimates or baseline assessments	Uncertainties are high as CER specifications are not available
Analogy	Reasonable quick and based on actual data	Subjective adjustments
	Requires few data	Accuracy depends on similarity of items
	User knows the origin of the estimate	Difficult to assess effect of design change
	No requirement of full understanding of problem	Blind to cost drivers
	Accurate for minor difference from analogous case	More difficult than parametric method as this required cases database, similarity measure, adaption functions and case indexations
	Good for rough order magnitude estimates, in absence of adequate data	Does not handle innovative solutions
Analytical	More accurate than analogy and parametric methods	Slow execution
	Detailed breakdown useful for negotiation	Detailed data may not be available
	Suitable when all characteristics of product and production process are well defined	Inappropriate for estimation at design stage
		Inaccurate allocation of overheads
Activity-based costing	Allocates costs according to where they are incurred	Time consuming
	Improved accuracy and relevance	Costly to implement and operate
	Details the causes of costs and gives a stronger indication of potential profitability	Difficulty in making it the only costing method
		Allocation of overhead is complicated

Figure 18: Comparison of different product cost estimating techniques (Partha and Rajkumar, 2010, p.146)

3.3.4 Establish the method of LCC formulating

The last step of Harvey's LCC procedure is to establish the method of LCC formulation. In this step, an appropriate methodology has to be chosen. With the chosen methodology, the LCC assets can be evaluated. Kaufmann developed the most original contribution to LCC knowledge, a can be seen in figure 19. He developed a process made up of an eight step formulation (Woodward, 1997, pp.336-337):

- Establish the operating profile
- Establish the utilisation factors
- Identify all the cost elements
- Determine the critical cost parameters
- Calculate all costs at current prices
- Escalate current costs at assumed inflation rates
- Discount all costs to the base period
- Sum discounted costs to establish the net present value

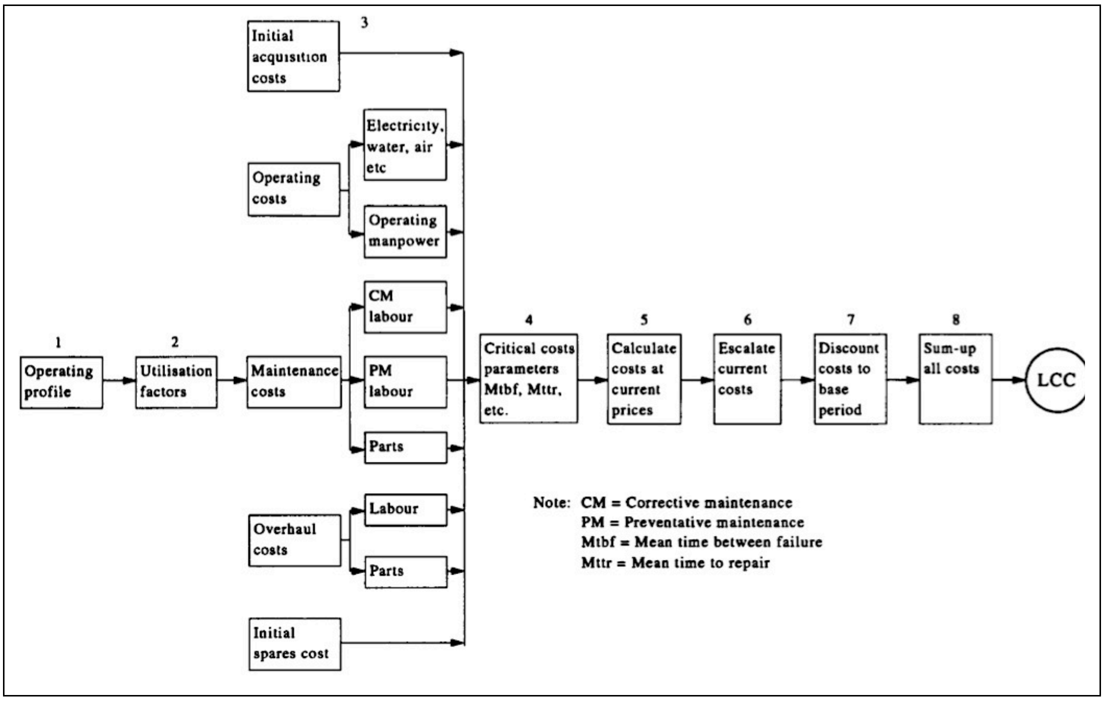

Figure 19: Kaufman's life cycle costing formulation (Woodward, 1997, p.337)

1. Woodward's formulation starts with the operating profile (OP). This describes the operation cycle which the equipment will go through. It starts with the ramp up of the production and ends with the shut down. It will show when equipment is working or not working. In other words, this indicator shows the proportion of time for which the equipment is operating or not operating (Woodward, 1997, p.337).

2. The second step is to determine the utilisation factor. This is an indicator of the performance of the machines. Sometimes it is not possible to perform all assets with 100% of the possible machine capability, sometimes the assets need to be performed more slowly, that means the utilisation of this machine cannot be 100%. Furthermore, a machine may not be able to work continuously, for example to change the assets, set up time, and maintenance (Woodward, 1997, p.337).

3. After the determination of the operating profile and the utilization factor, the third step in Kaufmann's formulation is that all the costs or areas of costs have to be identified. This includes initial acquisition costs, operating costs, maintenance costs, overhaul costs and initial spares costs (Woodward, 1997, p.337).

4. Step four includes determining the critical cost parameters. These costs are those that control the degree of the product costs incurred during the life of the equipment. The most significant cost parameters are mentioned below: (Stevens, 1997 citet in Woodward, 1997, p.337)

- Time period between failure;
- Time period between overhauls;
- Time period of repairs;
- Time period of scheduled maintenance
- Energy use rate

5. After this, the costs need to be calculated, which happens at that current time (Woodward, 1997, p.337).

6. But this is not accurate enough, so step six provides a projection of the future costs according to the right rates of inflation. This step should not be underestimated, since a lack of precision will lead to in-accurate financial results. This step is necessary most of the time, especially if the project will be produced in the distant future. Otherwise the inflation rate will be so small that it will not be useful to take it into account (Woodward, 1997, p.337).

7. The penultimate step takes into consideration the time value of the money. The cash flows, which occur in different periods, should be discounted back to the base period to guarantee comparability. Establishing the rate is very difficult and is one of the most discussed topics in the financial world (Woodward, 1997, p.337).

8. The last step sums up all the cash flows, which are involved in producing the asset. The summation of all of these steps is the Total Life Cycle Costs. With that result, the comparison between competitive assets can be started (Woodward, 1997, p.337).

With the LCC approach, future costs can be identified, which can show all the costs at the present value with the help from discounting techniques (Woodward, 1997, p.337).

3.4 Conclusion

This thesis deals with the implementation of LCC in MPM, which requires having some background knowledge such as was provided in the previous sections.
The life cycle acts as an introduction and subsequently the LCC was developed. One problem that occurs with LCC methodologies is a lack of data for obtaining an accurate result this can be solved with the data from MPM and this is also the reason why it is necessary. Another reason is to improve the MPM process with the factor cost because in the current environment, cost is a domain factor in nearly every successful business.
MPM offers a lot of data that is required for an LCC calculation but there is a lack of methodologies or tools to make use of all these factors. For this reason chapter four provides a tool, which incorporates and takes advantage of both.

4 Methodology for Life Cycle Costing's Integration in Manufacturing Process Management

The author of this master thesis believes that an integration of cost estimation approaches in MPM can be a really useful decision support tool as being aware of the manufacturing costs in the early product development stage is essential for effective and efficient competitive production and operation.

4.1 Introduction

The importance of LCC in MPM is the necessary early knowledge of costs in the design phase. Usually, designers put a lot of effort into designing the function and the appearance of a product but how to produce or even how to assemble is over-looked or not considered. Therefore, it is of the highest importance to have early information in the design phase. A lack in information could result in high labour involvement and higher manufacturing costs. Discovering it early would help to avoid unnecessary work in resolving manufacturing problems. Additionally, the design changes after a certain development phase are really hard to implement and can even lead to higher costs. For these reasons, it is essential to provide a manufacturing process manager with accurate cost information so that items can still be altered in the early development phase, there is a good overview of the future product and possible costs that could result in an advantage against competitive enterprises are also recognised.

This section starts with the requirements for an early decision support tool and after that discuss where the costs originate. Finally, the methodology will be introduced, which provides a solution for LCC in MPM. After the description, integration follows.

4.2 Requirements for an efficient early decision support tool

The following list of requirements is needed to fulfil an efficient early decision support tool. As mentioned before, around 70% of product cost is influenced in the early product development phases. For that reason the requirements are adapted for less information because in this stage, a lack of information exists. However, the level of information increases with the progress of the product.

- Be able to change the processes, with a direct link to the costs, to always find the best solution
- Be able to have a link between the redesign of the product and the changes of the costs
- Be able to imply the user in all steps
- Be able to decide with the help of indicators for quicker decisions
- Be able to provide a visible cost structure for the MPM engineer to track the costs and understand it better.

These requirements have to be taken into consideration by developing such a methodology, which implements LCC in MPM.

4.3 Cost Contributions

In order to be able to estimate the costs of a whole product, costs must be divided into tangible magnitudes, such as manufacturing costs, assembling costs, material costs and purchased components. The main cost contributors are illustrated in figure 20.

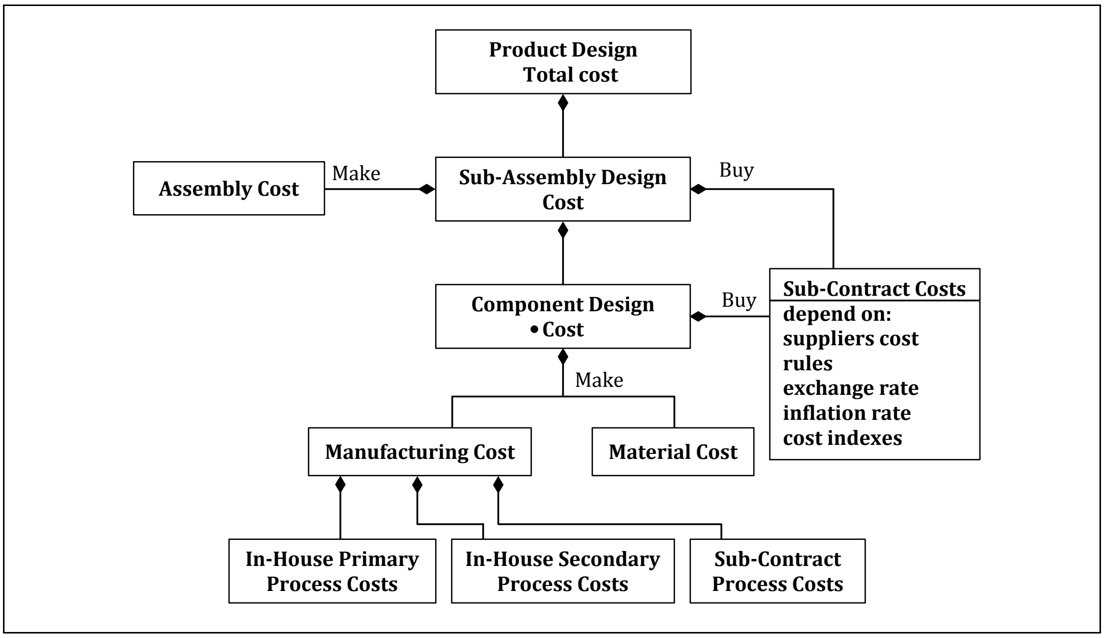

Figure 20: Cost contribution (Rehman and Guenov, 1998, p.624)

It can be seen that estimating the costs of a product is not very easy because there are several internal and external dependencies. The problem domain is made up of a large number of items, which interact in a complex way and the integration of a variety of information is required (Rehman and Guenov, 1998, p.624).
All these areas have to be taken into account by developing a cost estimation approach in the design phase.

4.4 Methodology of Life Cycle Costing in Manufacturing Process Management

The methodology of LCC in MPM is based on Harvey's LCC procedure but adapted to the area of Manufacturing Process Management.
Step one defines all the cash flows, which occur in MPM. Step two is already described through MPM because this step is responsible for defining cost structures but within MPM, the cost structure is characterized with engineering and development cost. The result, which I obtained in step three, is a combination of a quantitative cost estimation approach (Case Based reasoning) and a qualitative cost estimation approach (Activity Based Costing). The advantages of this combination are described in detail in section 4.5.2. The last step of this methodology is discussed in the following section (Figure 21).

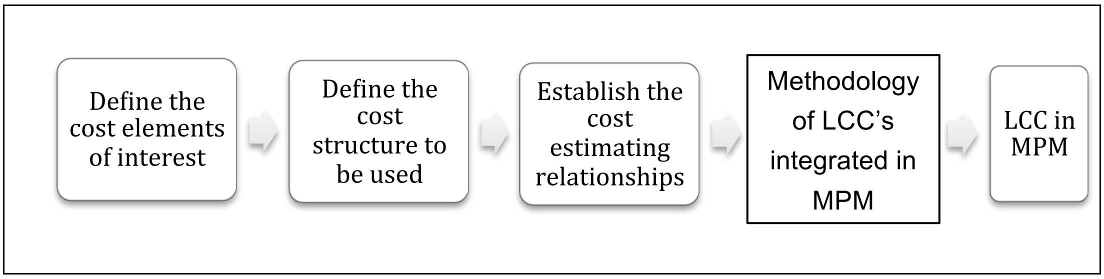

Figure 21: Harvey's LCC procedure (adopted from Woodward, 1997, p.336)

4.4.1 Harvey's step 4, establish the method of Life Cycle Costing formulating

Figure 22 illustrates the framework of the implementation of Life Cycle Costing in Manufacturing Process Management area. The methodology integrates two different cost estimation approaches (Step 2) and a decision tool (Step 3) on whether to purchase components or produce within the factory. At the centre is a database, which provides information about previous cases and learns from newly solved problems.

This approach starts with the dissembling of a product into its smallest parts. Each item is then examined separately (Step1).

After that, a qualitative cost estimation approach (Case Based Reasoning) will check to verify if this item has already been manufactured, in order to find out whether a case already exists in the database or if it is a completely new part design. In the case of a new part design, CBR is not helpful and a quantitative cost estimation approach (Activity Based Costing) has to determine the details of the costs. When the costs are determined the backup will be placed in the database for subsequent cases.

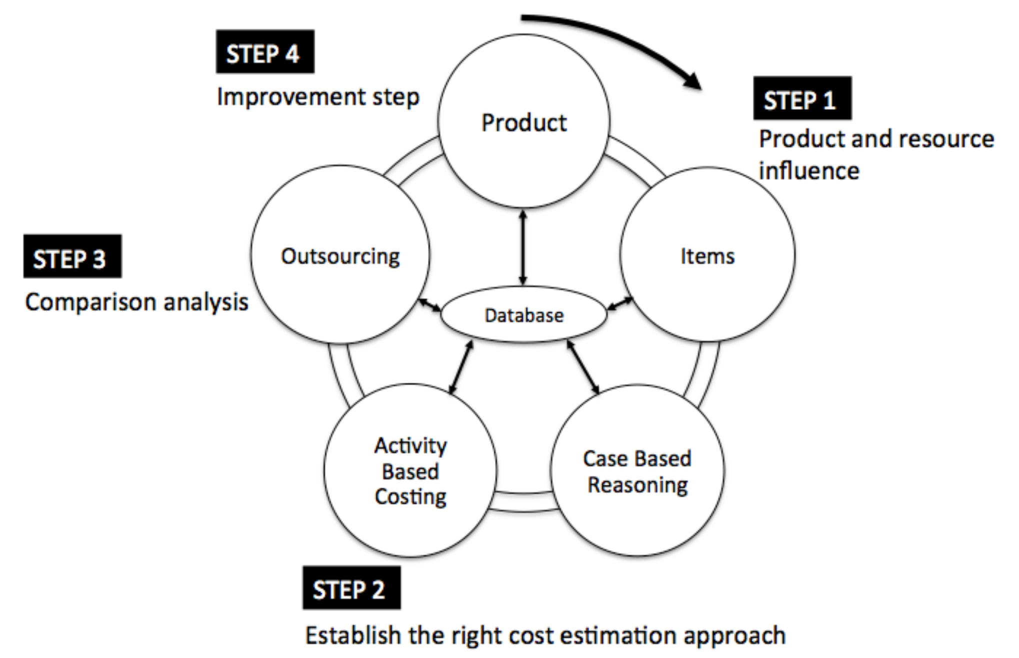

Figure 22: Methodology of LCC's integrated in MPM

Step 3 describes an outsourcing decision, where the MPM engineer has to compare the manufacturing costs with the purchasing costs. If outsourcing is chosen, the costs of the purchased items or groups will be stored in the database.

Finally, in step 4, the total production costs of one product are determined and the MPM engineer or manager has to decide if it is a suitable price or if improvements could achieve a better cost. They then make the decision of whether the product should go into production or into the improvement cycle.

Figure 23 provides a detailed view on the methodology with all the necessary participants and the different kind of flows, such as cost- information- flow, basic data flow and the flow of the view of the product.

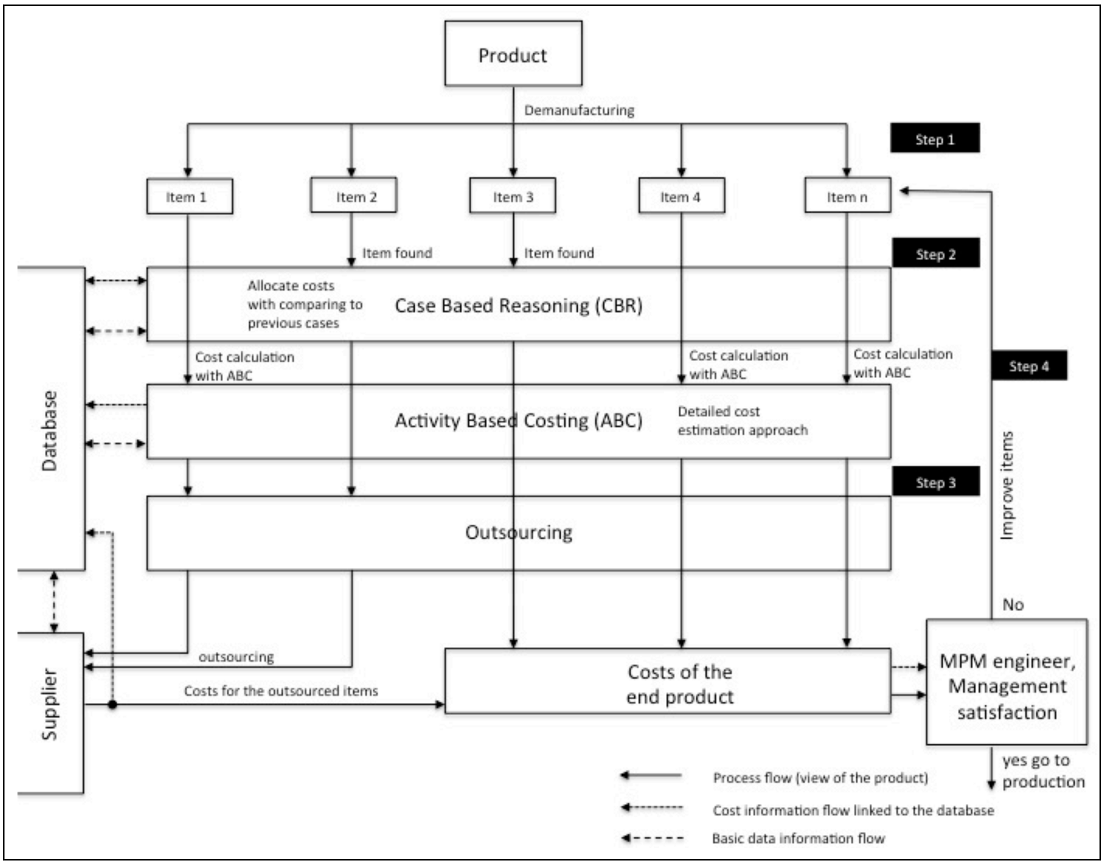

Figure 23: Methodology of LCC's integrated in MPM

The proposed steps will be described further in the following sections.

4.5 The integration of Life Cycle Costing in Manufacturing Process Management

The success of the integration of LCC in MPM depends on the information and data, which are required to perform accurate cost estimations, support decisions that improve the product i.e. reducing costs, improving quality, and shortening the time to market. Furthermore, rational decisions can only be based on information.

4.5.1 Step 1: Product and resource influence

The following basic data are required:

- **Item data**

Item data is basic information that an item can explicitly be identified by, such as weight, description, a specific number (item number), unit of measurement etc. (Jonsson and Mattsson, 2009, p.66; Jack, 1996, p.70).

- **Bill of material data**

This information describes how a product is structured or how products have to be assembled, such as purchased items, manufactured semi finished components, raw material, etc.; (Jonsson and Mattsson, 2009, p.66; Huet, et al., 2009, p.2; Shalvi, 2003, p.4)

- **Routing data**

Routing data consists of the information of how a product has to be manufactured and which resources are required to fulfil the manufacturing process; (Jonsson and Mattsson, 2009, p.66)

- **Work center data**

This data describes which resources are needed by the company, if they are available and their capacity and performance (Jack, 1996, p.70; Jonsson and Mattsson, 2009, p.66).

The interaction between these different types of data can be seen in figure 24. The work centre data requires information from the routing data, which makes different stages in production easier to visualize. The routing data requires information from the Bill of Material data; this connection enables material to be related to the production. The item data is needed for the bill of material to illustrate the structural definition of the product. Further, all items are described. The connection between the routing data and the item data brings together specifications for the manufacturing process of a certain product. All of this is required to be able to plan a complete process plan for a certain product (Jonsson and Mattsson, 2009, p.66).

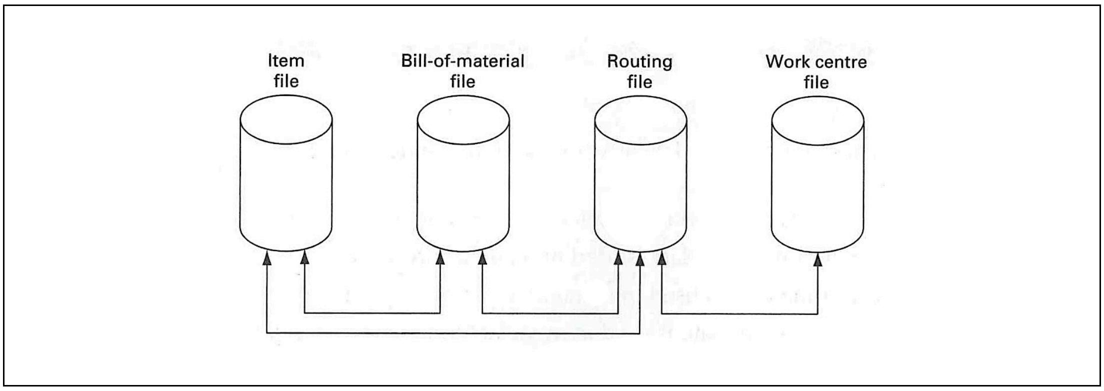

Figure 24: The relation ship between different basic data files (Jonsson and Mattsson, 2009, p.66)

4.5.2 Step 2: Establish the right cost estimation approach

With this information, a basis for the methodology can be found. After that, Harvey's (1976, pp.343-347) LCC procedure has to be followed. In his third step, he describes how to establish the cost estimation relationship, find an appropriate cost estimation method, which will fulfil all the needs and requirements dependent on the development stage of the product.
As can be seen in figure 25, the cost estimation methods occur in different phases of a product.

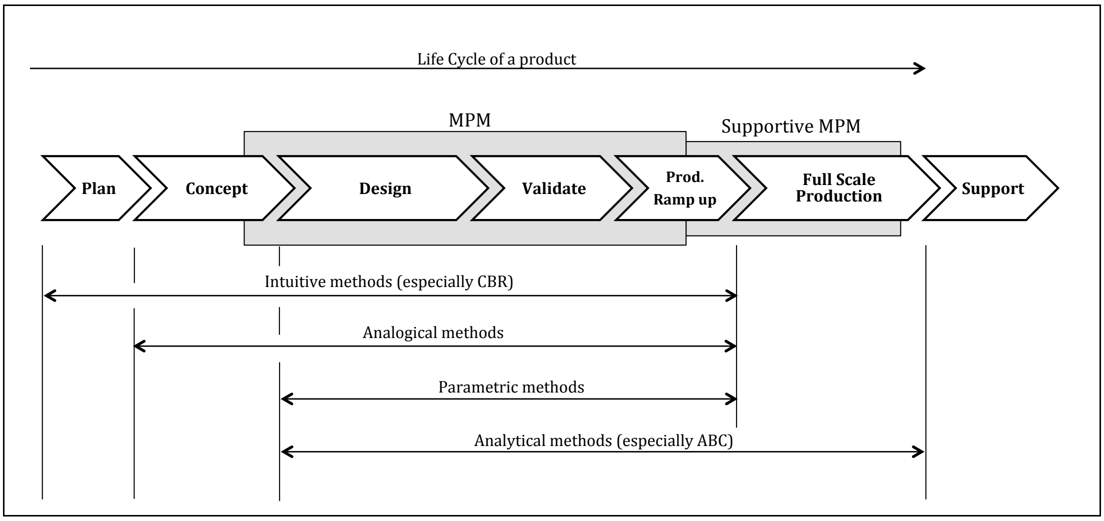

Figure 25: Area of use of cost estimation approaches (especially CBR and ABC) (adapted from Duverlie and Castelain, 1999, p.1329)

Duverlie and Castelain (1999) start by defining it and end with the manufacturing process. The information stream increases after each step, as more and more decisions are made until the product is completely ready to fabricate.

MPM is between the concept area and the production area. This means, according to Duverlie and Castelain (1999), that both the quantitative and the qualitative cost estimation methods can be implemented. The author of this thesis decided to take one from each, a detailed cost estimation (ABC) and an intuitive model (CBR) based on previous knowledge.

The reason for this is that in MPM, a combination of a detailed analysis (ABC) and a tool, which provides information from previous cases (CBR) matches the best for the given task. From the view of an MPM engineer it provides advantages in preceding the methodology. I obtained this result in two ways: The first one, the view of an MPM engineer; and the second one, with an excluding principle.

The parametric cost estimation approach, for example, can be excluded as it defines parameters, which do not describe the product but only characterize it, so it is quite hard to apply it in big companies with different products and changing production. Furthermore if some parameters are not applied and if they become important, it would be a disaster and lead to inaccurate costs.

According to MPM, a manufacturing engineer gets a 3D model of a part to start his work. Case Based Reasoning is able to estimate costs from similar parts, which could be available in the database. If the search results are negative, the engineer needs to estimate with the help of Activity Based Costing. Which results in a really detailed and accurate outcome of cost, for the item. Figure 26 shows where the two approaches are placed.

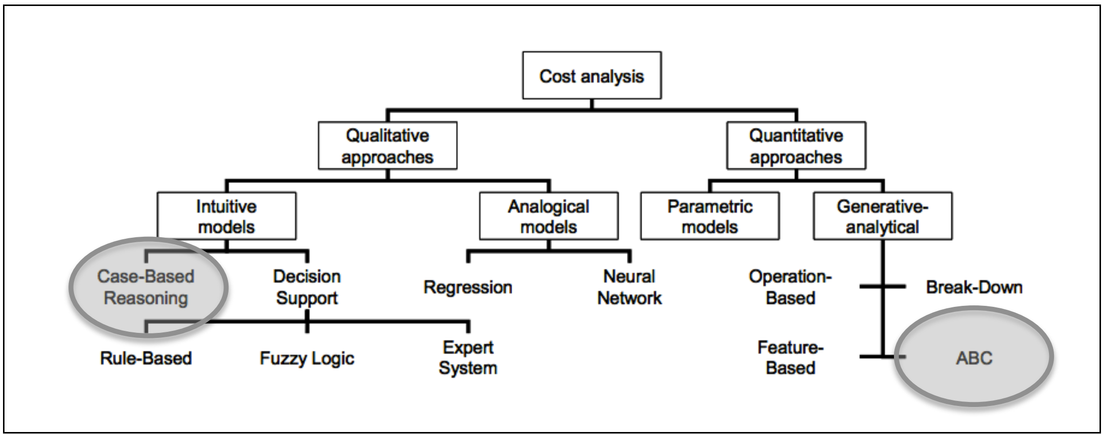

Figure 26: Classification of cost estimations approaches (Niazi, et al., 2006, p.567)

The database is the heart of the methodology. The results, which are obtained with ABC, will be stored in the database. This is because CBR requires a well maintained extensive database in order to be able to find the most similar cases. And after the adaption of the cases, it will also be stored in the database. CBR and the database have an extensive interaction, where ABC has a one-way information stream, namely to the database.

4.5.1 Step 3: Comparison analysis

After the costs for each item are determined, a comparison of suppliers can start. If it is an advantage for the companies to outsource then they should outsource but if there are disadvantages linked to outsourcing, then it should be reconsidered. The outsourcing decision and its possible issues will be discussed more thoroughly in the next section.

Outsourcing

Outsourcing has become more and more important in the management of business strategies. Over the past years, the discussion about outsourcing has increased dramatically. A frequently occurring issue for a manufacturing company is whether to outsource or to take care of the manufacturing in house. The company compares it's own manufacturing costs for one part with the price they would pay to a supplier for manufacturing the same part for them (Hicks, 2002, p.133).

Activities that would perhaps be outsourced can be severely affected and could harm the enterprise if outsourced. This means that, if an activity has long-term strategic importance for the company, for example, it would create counter-productive effects. In order to stay competitive a company should never outsource any activities in which it has specialised knowledge or skills: e.g. a company, which produces laser printers and may have specialised knowledge in producing a sophisticated laser driver. The potential of that knowledge may be able to develop future innovations. To outsource under these circumstances would not be in the company's best interests. In order to make the right decisions, figure 27 illustrates a framework that supports the outsourcing decision (Slack, et al., 2009, p.145; Hicks, 2002, p.134).

The first two questions been discussed previously; the third one contains the operation performance. If the performance is superior, the decision should be to keep the work in house instead of outsourcing. The last question in this framework discusses the improvement factor. If improvements of these activities is likely, then it is best to keep the work in house in order to define new innovations in the future using specialised knowledge (Slack, et al., 2009, p.145).

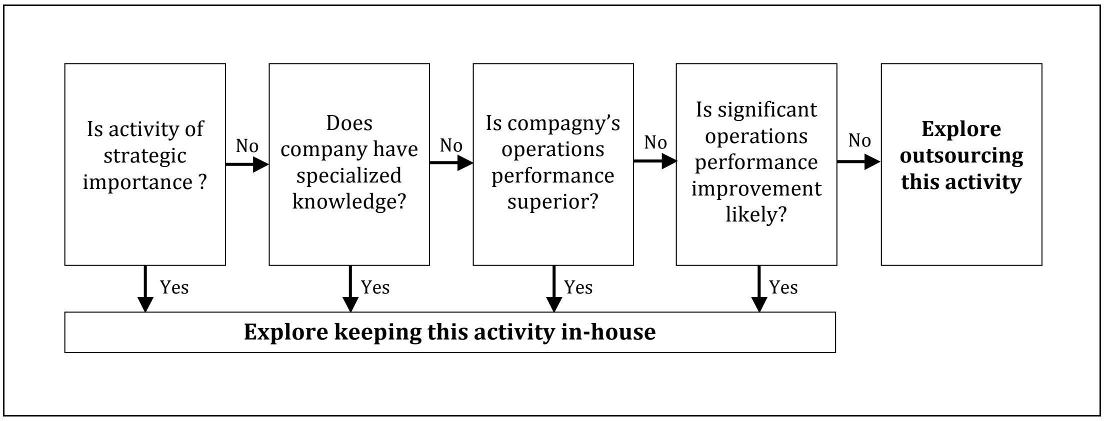

Figure 27: The decision logic of outsourcing (Slack, et al., 2009, p.145)

Hicks (2002) shared a good example of a client, who made the wrong decision to outsource. This client manufactured a product at a fully absorbed cost of about $5. They produced 20000 units of this product each year. Another company proposed that they could produce it for 4 dollars. His client's company could save $20,000 each year, so the decision was made to outsource and the other company got the order. However, eliminating the $5 cost of the item production does not mean that all the involved costs in the manufacturing are eliminated. More than half of the $5 includes distribution from support activities. Correspondingly, $2,50 of each unit's costs cannot be eliminated. The result was that the cost for one item became $6,50 instead of $5 because they decided to outsource. The annual losses were $30,000.

In fact, items are outsourced too often when enterprises discover that a supplier can deliver more cheaply than they can produce.

In order to avoid making the wrong decisions, it is necessary to look at the costs in detail. Currently, outsourcing is usually the right decision but only after an accurate comparison with precise cost information in order to avoid making the same mistakes that occurred in the example (Hicks, 2002, pp.133-134).

4.5.2 Step 4: The improvement step

After calculation of the product costs, the managers or the MPM engineers can decide if it is too expensive or if they will need to change something in the design plans to obtain a more desirable price for an individual item. It always returns to step one and is a never-ending cycle of improvement.
Deming founded this cycle of continuous improvement starting with "plan" and followed by "do," "study," and "act", as illustrated in figure 28. These four steps are adapted to the proposed methodology (Bergman and Klefsjö, 2010, p.455; Slack, et al., 2009, p.544).

1. The enterprises should **"plan"** which items or products are of interest to be able to plan the processes and all that is linked to production.
2. The enterprises should **"do"** the cost estimation of the chosen items or products. The result of this step should be an exact estimate of how much it would cost for an enterprise to manufacture the product.
3. The enterprises should then **"check"** the result to see if it is suitable enough and if they can profit from it.
4. If the result is not acceptable the enterprises should **"act"** and start again with step number one and this is called a cycle of continuous improvement.

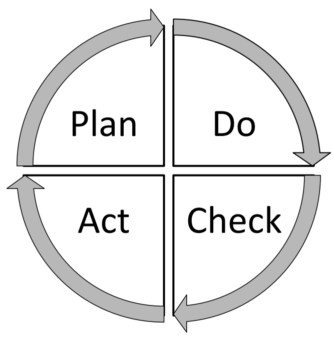

Figure 28: The Deming cycle Improvement Cycle (Bergman and Klefsjö, 2010, p.455)

This cycle should be completed as often as necessary, until an acceptable result occurs. It is also important to mention that a cycle of continuous improvement should not only be applied to products but also to processes, systems, and measurement systems, such as this next approach (Emblemsvåg, 2003, p.180).

4.6 Conclusion

This section provided a detailed overview of the implementation of LCC in MPM. It has also been discussed according to Harvey’s LCC framework. The next section will introduce the two chosen calculation methods that are ABC and CBR in more detail.

5 Implementation of cost estimation methods for Activity Based Costing and Case Based Reasoning in Manufacturing Process Management

Section 5 of this thesis provides a detailed description of the implemented cost estimation approaches ABC and CBR in the methodology.

5.1 Case Based Reasoning (CBR)

In 1977, Schank and Abelson founded Case Based Reasoning, which is provided in the following section.

5.1.1 Introduction

CBR is a developed approach for problem solving and learning that has grown over the past years from a rather specific and isolated field, to a widely discussed research area. CBR is able to solve problems with previous experiences. It is utilizes the specific knowledge from previous cases to determine the new case. Finding the most similar past cases solves a new problem and these are used for the case at hand. The other main point of CBR, after problem solving, is the incremental sustained learning effect from the compounding knowledge gained from each solved case. After solving new problems, the CBR approach saves the data so that it can be provided for future cases. The availability of the new solutions is essential for a good working case based reasoning approach (Aamodt and Plaza, 1994, pp.2-6). Riesebeck and Schrank defined a Case Based Reasoner as:

> “A case-based reasoner solves new problems by adapting
> solutions that were used to solve old problems”
> (Riesebeck and Schank, 1989 cited in Aamodt and Enric, 1994, p.6)

The biggest advantage of having learned to solve problems through previous experience is that it will be possible to find solutions for future cases more quickly.

5.1.2 Case Representation

A case is a representation of experience and contextualized pieces of knowledge. It contains:

- **The problem**: This describes the actual situation when the case occurred (Duverlie and Castelain, 1999, p.890; Watson, 1997, p.20).
- **The solution**: It describes the appropriate solution to the previously discovered problem (Duverlie and Castelain, 1999, p.890; Watson, 1997, p.20).

A good visualization can be seen in figure 29; it contains a problem space and a solution space. Moreover, it describes that an individual case consists of a problem description and a stored solution. If a new problem occurs, this one will be placed within the problem space. The retrieval process will identify the most similar cases based on the problem description and will find a suitable, stored solution. This is illustrated with an arrow (Labelled “R”). If the solution is not suitable enough then an adaption could occur and create a new solution (Arrow “A”).

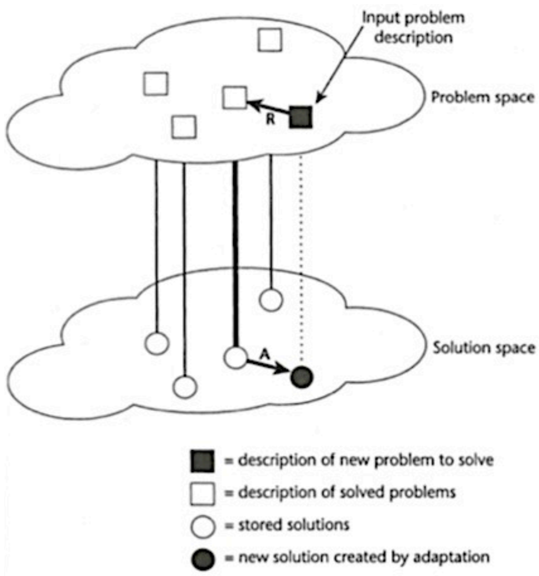

Figure 29: The problem and solution spaces (Watson, 1997, p.20)

A conceptual model of Case Based Reasoning shows the direct link between the problem area and the solution area.

In fact, for each case, most of the data can be stored, for example in a conventional database, such as product identifiers, names, textual notes, and specific values like temperature or costs.
One of the main questions is, what information should be stored in a case. Watsen (1997) mentioned two different but equally important points that should be taken into consideration when deciding what the necessary information is. The data represents the information for cases. The information should be: (Watson, 1997, p.22)

- Functional
- Easy to purchase if it is needed

5.1.3 The Principle of Case Based Reasoning

Figure 30 illustrates the principle procedure, which defines Case Based Reasoning. The principle of CBR is based on dependent relationships between the problem and previously solved problems. Actually, there are two cases that exist, the source case and the target case. The first one is the well-known case. Everything within it is well defined and it will be used to find the solution for the target case, which is the second one. The cases will be compared and if they are similar, the same solution will be proposed to solve the target case (Aamodt and Plaza, 1994, pp.2-4; Duverlie and Castelain ,1999, p.898).

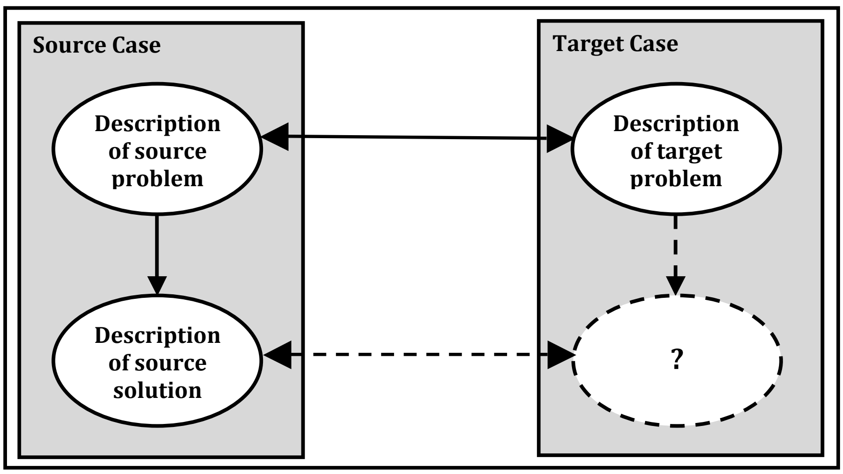

Figure 30: The Principle of Case Based Reasoning (Duverlie and Castelain, 1999, p. 898)

5.1.4 The descriptive framework

Aamodt and Plaza developed a framework for describing CBR methods and these systems contain two main points: (Aamodt and Plaza, 1994, p.7)

- **A process model for the CBR-cycle**
- **A task-method structured for CBR**

The two different models are complementary and they show two different views on CBR. The first method is a dynamic model that identifies the main subprocesses of a CBR cycle. The second method shows a task-oriented view. It is a task tree that is broken down and is described with related problem solving methods (Aamodt and Plaza, 1994, p.7).

5.1.4.1 The CBR-Cycle:

According to the example, the following four steps may describe a general CBR cycle or are also called the four RE's: (Aamodt and Plaza, 1994, p.8; (Ficko, et al., 2005, p.1331; Kolodner, 1992, p.22; Watson, 1997, p.34)

- **RETRIEVE** the most similar case or cases
- **REUSE** the information and knowledge to solve the problem
- **REVISE** the proposed solution
- **RETAIN** the parts of this experience that are likely to be useful for future problem solving

To solve a new problem, previous experienced problems are retrieved and reused. It is also possible to revise solutions to adept it and that the result of the case is more suitable. Finally the new gained experiences are retained in the existing knowledge base. Each of these four processes consist of several more specific sub- steps, which are described in the task model. Figure 31 illustrates the CBR-Cycle. As can be seen in it, everything starts with the specification of a new problem and this problem defines a new case. This case is used to retrieve old cases, which are collected in the database and the database has learned from these old cases. Picking out similar cases from memory is one of the essential elements. After that step, the retrieved case is compared to the new case and through reuse it is transferred into a solved case. In this step a suggested solution is proposed for the given problem. The revise process is responsible for testing the new solution for its success. For example, it is applied in the real world situation and if it fails, it will be repaired. Obviously, the confirmed solution is the result. The last process in the CBR-Cycle is called "retain". This is one of the most important processes. Through the retain process, useful data taken from experience is retained for future reuse, or by modification from old cases. Finally the database is updated. This is what characterizes a continuously incremental suitable learning process (Aamodt and Plaza, 1994, p.8; (Ficko, et al., 2005, p.1331; Bergmann, R., 2003, pp.15-16).

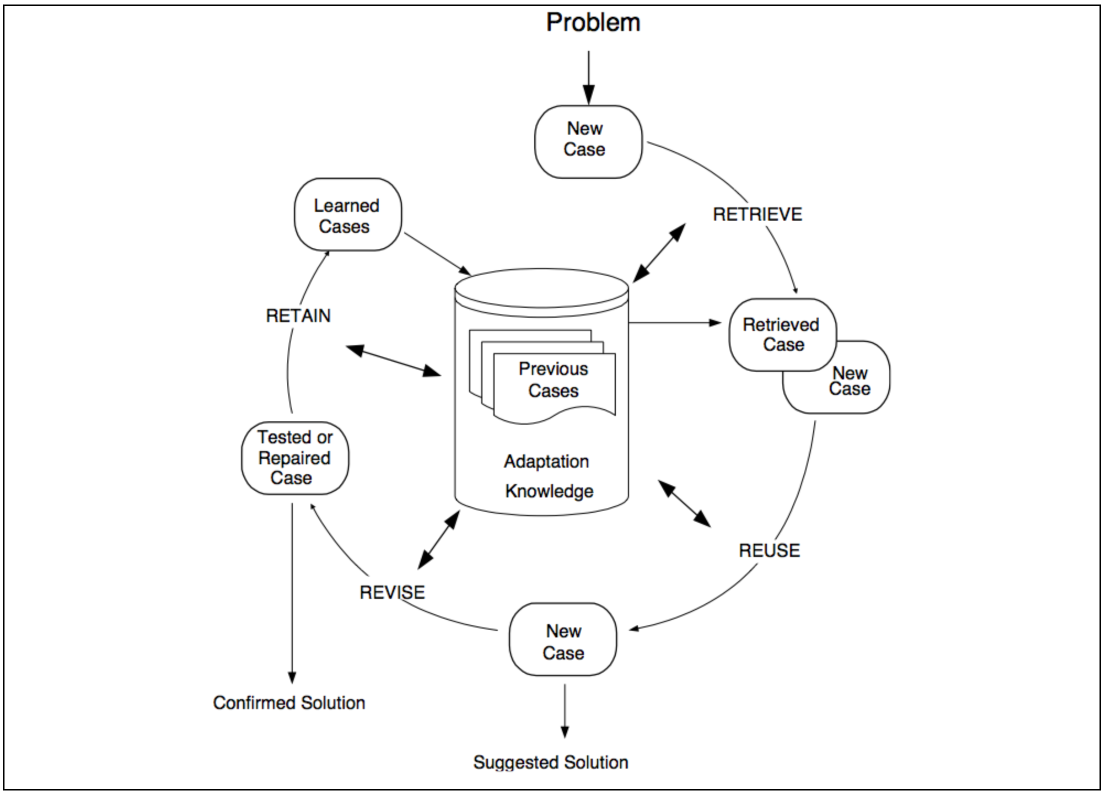

Figure 31: Reasoning Cycle in CBR (Vong, et al., 2003, p.569)

As illustrated in the figure 31, the adaption knowledge usually plays an important role in the CBR-Cycle by supporting all the different steps. It is the heart of the CBR-Cycle (Aamodt and Plaza, 1994, pp.8-12). However the cycle rarely works without human intervention (Watson, 1997, p.15).

5.1.4.2 The hierarchy of CBR tasks

This process view has just described the main sequential processes in the CBR-Cycle but to see more than just these four top-level steps, it is necessary to switch to a task oriented view. In this view, each of the RE's is broken down and all the subprocesses are seen as tasks. Furthermore, each of these tasks has to be achieved by the Case Based Reason reasoner. While a process oriented view is useful in the sense of presenting a global external view of how it works; a task-oriented view is more suitable for describing the details. The task-oriented view shows the perspective of a CBR reasoner (Kolodner, 1992, p.23; Watson, 1997, p.34).

A system can be seen from three perspectives:

- Tasks
- Methods
- Domain knowledge models

Tasks are set up by the goals of the system and one or two methods are applied to perform a task. To fulfil a task, the chosen method needs to be fed information about the current problem as well as the general knowledge application domain (Aamodt and Plaza, 1994, p.9).
Figure 32 illustrates the task-method structure.

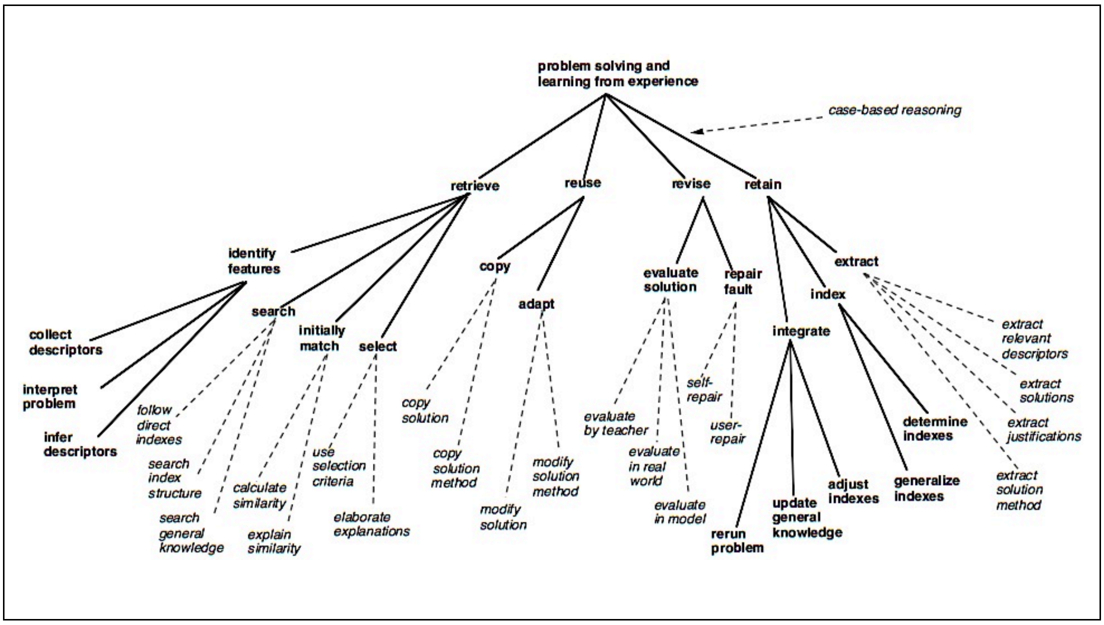

Figure 32: A task-method decomposition of CBR (Aamodt and Plaza, 1994, p.10)

The bold letters illustrate the tasks, while the methods can be identified by italic letters. The task decomposition is the link between the task nodes (plain lines). As illustrated in figure 32, everything starts with problem solving and the accumulated knowledge from past experiences, which is on the top level of the task method structure. The method, in which to fulfil the required tasks, is case based reasoning. In the next level are the four major tasks of Case Based Reasoning corresponding to the processes in the CBR-Cycle: retrieve, reuse, revise and retain. All four of these tasks are very important in being able to perform the top-level task. In order to fulfil the retrieval step, the subtasks must be carried out, beginning with the search to find an appropriate past case. After a successful search, the initial match task follows. In this step, the relevant descriptors from the past cases are allocated and the similarity is calculated. Finally, the selection of the most similar cases completes the Retrieve task (Aamodt and Plaza, 1994, p.9).

5.1.5 Retrieval

Picking out previous cases from the database is one of the most essential parts of CBR. This requires special attention to the similarity calculation and the indexes that are given. The retrieval process starts with a given problem description and ends with finding the best matching previous case. This main task can be divided into four subtasks:

- Identify features
- Initial match
- Search
- Select

These subtasks are performed in the given order. The identification task is responsible for finding features that can be compared in the matching task to find the best matching cases. The selection task selects the most similar, which correspond to the new case in the best way (Aamodt and Plaza, 1994, p.14; Kolodner, 1992, pp.22-23; Watson, 1997, p.23)

Storage

The database is the heart of CBR, all the necessary data, which is needed to retrieve a case, has to be stored in it. Storing this data is an important aspect in defining a CBR system. It should be stored in a structurally manageable way in order to have an easy, fast and efficient search result. The storage and retrieval works in conjunction with indexing (Watson, 1997, pp.22-23).

Indexing

Indexes are the most common use for databases systems for increasing the efficiency of the retrieval process. An index is a computational data structure, which can be held by memory and makes it is easier to find things. This means that the computer does not need to search each and every record stored on disk, which would take much longer. Indexes are also used in CBR to retrieve the data faster. The information that a case contains comes from two different sources (Kolodner, 1992, p.23; Watson, 1997, p.23):

- **Indexed information** which finds similar cases (Retrieval)
- **Unindexed information** that is not used in retrieval but contains additional information that may have some sort of value for the users.

Indexed information in a medical system could be the age, weight, size and sex of a patient. From which, these indexed features can be called upon for retrieval. A photograph of the patient, for example, would be un-indexed information. The photograph can only help remind the doctor who this patient is. It cannot be used for refining similar cases (indexes) (Aamodt and Plaza, 1994, p.18; Kolodner, 1992, p.24; Watson, 1997, p.23).

Four guidelines provide instruction on how to design indexes:

1. Indexes should be predictive
2. Indexes should clarify the purpose for which the case will be used
3. Indexes should be abstract enough to allow for future use
4. Indexes should be concreted enough to be identified in the future

An example to demonstrate this point would be a bank employee. If an employee of a bank wants to know if a client can repay their loan, he needs predictive information, which would not be the name, age, or telephone number, rather the address. This could help determine if the client lives in an upmarket region. Real predictive information would be the income and or existing financial commitments (Watson, 1997, pp.20-21).

Nearest Neighbour Retrieval

The Nearest Neighbour retrieval is a very simple approach and easy to understand. The bank manager example will be used in the following paragraphs to describe how it works (Athitsos, 2008, p.328).

.

In this case, the main question for the manager is if he should grant a loan to a client or not (Watson 1997, p.24).

The first step is defining the indexes that would allow a comparison of different loans. As mentioned in the previous section, the indexes should follow four guidelines. The best matching criteria for the indexes that correspond to the guidelines are:

1. The net monthly income of the client
2. The monthly repayments on their loan

These two features are used as indexes, usually it is more complicated and there could be several indexes.

Figure 33 illustrates the two indexes as axes. The x-axis represents the net monthly income and on the y-axis is the repayment for the loan (Athitsos, 2008, p.328; Watson, 1997, pp.23-24).

Bad loans and good loans are also plotted on the graph, all this knowledge about these cases came from previous experience. These indexes are very predictive because common sense indicates that, if the income is high and the repayment of loans is low, then it is more likely that the loan can be repaid than if the reverse were true.

As can be seen, this graph is logical and it can be used as a decision support tool for future cases (Watson, 1997, pp.24-25).

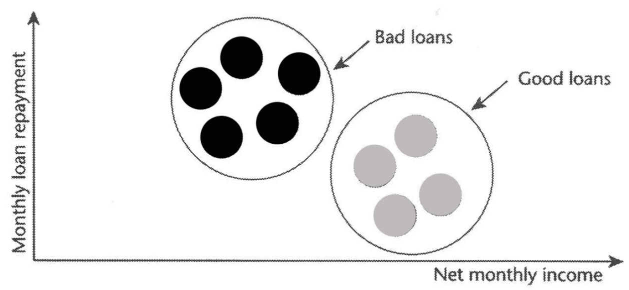

Figure 33: Cluster of good and bad loans (Watson, 1997, p.25)

After clarifying this graph, all prospective clients would only need to give their monthly income and their monthly repayment on their loans. From this the bank manager would be able to immediately say if the client will be able to successfully repay the loan or not. If the plotted point of the client is in the "good loans" area the manager can grant his client the loan, if not then he should refuse to grant it.

Figure 34 shows a client who is between the "good loan" and the "bad loan" areas, however, to be certain; the distances between the client and the areas can be calculated. Finding the relative x and y distances from the target case to the sources cases would do this. (Watson, 1997, pp.23-24)

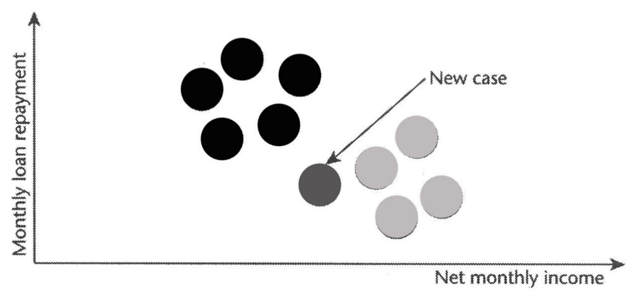

Figure 34: The target case between the source cases (Watson, 1997, p.25)

Figure 35 illustrates the simplification of the previous figure; the areas are now condensed into one source case (A and B). Source case A represents a good loan and source case B represents a bad loan. It now becomes easy to obtain the distances:

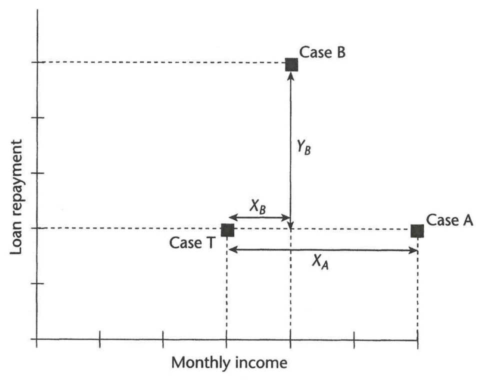

Figure 35: A graph with nearest neighbour distance (Watson, 1997, p.26)

The distance from A to T is $d_A=X_A+Y_A$
The distance from B to T is $d_B=X_B+Y_B$

As a result, the smallest distance will reveal the nearest neighbour and a conclusion can be drawn. Case T is closer to the source cases A, the result of this study is that the client will get his loan.
In fact, usually there are more than ten to twenty indexes used, all with different weights. This is necessary to ensure that the best realistic result is obtained and for making the right decision. Instead of only having two dimensions, there can be an n-dimensional space (Watson, 1997, p.26).

Measure of similarity
In CBR, the aim of numerical similarities is to measure resemblances, which exist between the cases. However, to calculate the nearest neighbour or to find the most similar case, the most general given equation below has to be solved (Watson, 1997, p.28; Duverlie and Castelain, 1999, p.899).

Equation 5: Measure of similarity in CBR (Duverlie and Castelain, 1999, p.899)

$$Sim_{global}(X_1, X_2) = \frac{\sum_i p_i * Sim_i(X_1, X_2)}{\sum_i p_i}$$

p_i = weight of the attribute i
Sim_i =function of similarity of the attribute i

Adaption of the closest cases
Adaption is the last step in the retrieval process. After matching an old case, the CBR approach will reuse the suggested solution. The suggested solution can be close but sometimes it may not be close enough for the required target case. If this is the case, the CBR system has to adopt the source cases to get a better match to the target case. Adaption is applying rules, equations, or other techniques to take the differences into account in order to be able to calculate the costs of a product. Basically, it can be divided into two general adaptations in CBR (Aamodt and Plaza, 1994, pp.16-17; Watson, 1997, p.32):

- **Structural adaption** works with applying equations or adaption rules directly to the stored case in the database where the solutions are known.
- **Derivational adaption** works with reusing the equations and rules, which were previously used for the original solution to create a new solution. It can only be used if the domain is well understood.

Several techniques have been developed to adapted cases, ranging from simple to complex. Some are listed bellow: (Kolodner, 1992, p.25; Watson, 1997, p.34)

Null adaption does not add any adaption at all. It shows the closest solution to the current problem without changing anything. Null adaption is useful for really complex cases in order to have an overview, without any potentially confusing changes (Aamodt and Plaza, 1994, p.16; Kolodner, 1992, p.25; Watson, 1997, p.34).

Parameter adjustment is a technique from the structural adaption, which compares parameters from the target case and the source case to modify the solution in a good way (Aamodt and Plaza, 1994, p.16; Kolodner, 1992, p.25; Watson, 1997, p.34).

Reinstantiation compares features of the target case with the source case (Aamodt and Plaza, 1994, p.16; Kolodner, 1992, p.25; Watson, 1997, p.34).

Model guided repair uses a causal model to decide on the adaptions; it guides the adaption. This model requires a good understanding of the target case (Aamodt and Plaza, 1994, p.16; Kolodner, 1992, p.25; Watson, 1997, p.34).

While adaption is useful and necessary in many cases, it is not compulsory. Many of the most successful enterprises do not use the adaption of CBR because it may result in confusion. They either simplify their case to the proposed solution or they do it manually with the aid of employees. Once an adaption has been performed successfully, it will be stored in the database for future use. In this way, a CBR system is continuously learning and increasing the ability to solve future cases (Watson, 1997, pp.34-35).

5.1.6 Advantages and Disadvantages of the Case Based Reasoning

Case Based reasoning provides solutions very quickly. The origin of the proposed solution can, at any time, be easily identified and corrected. This makes CBR a transparent method.

CBR also collects and stores all the enterprise's knowledge and is available at any time for other users, who have not elaborated on these solutions. Fortunately, the knowledge remains within the company or in the department, even if the employee who developed the knowledge leaves.

CBR is able to solve cases that have been seen before and it stops people making the same mistakes (Bergmann, 2003, p.15; Duverlie and Castelain, 1999, p.900).

One of the major advantages of CBR is that this approach has the capacity to combine several methods in the penultimate step, which is the revision step. After selecting the most similar cases, the determination of the project or product costs can begin. This does depend, however, on the kind of information or data that is available in the database (Duverlie and Castelain, 1999, p.900; Kolodner, 1992, p.29).

The second major advantage of CBR is the indexation. With its help, it is possible to link the important parameters, such as costs of the studied products (Duverlie and Castelain, 1999, p.900).

The use of CBR in a company for cost estimation is not an easy task as a well-maintained database is the most required necessity of this technique. It is of the highest importance to provide the case bases with the indexation, the similarity calculation and the adaption function (Bergmann, 2003, p.15).

5.2 Activity Based Costing (ABC)

Over the past couple of decades, ABC method has grown from a rather specific research area to a field of widespread interest. It is rapidly growing as it can be seen by the increased share of papers at major conferences and successful applications in daily use. Cooper and Kaplan developed this approach in 1988, as an alternative possibility to traditional accounting techniques. Since it is introduction, this approach has been increasingly used in manufacturing enterprises (Özbayrak, 2004, pp.49-50).
ABC is a detailed cost estimation approach, which is based on activities, assuming that each activity is consuming resources. The driving force behind its development was the need to control and understand indirect costs. Overhead costs are traced to a specific item. ABC is a high-power decision support tool (Park, 1995, p.440).

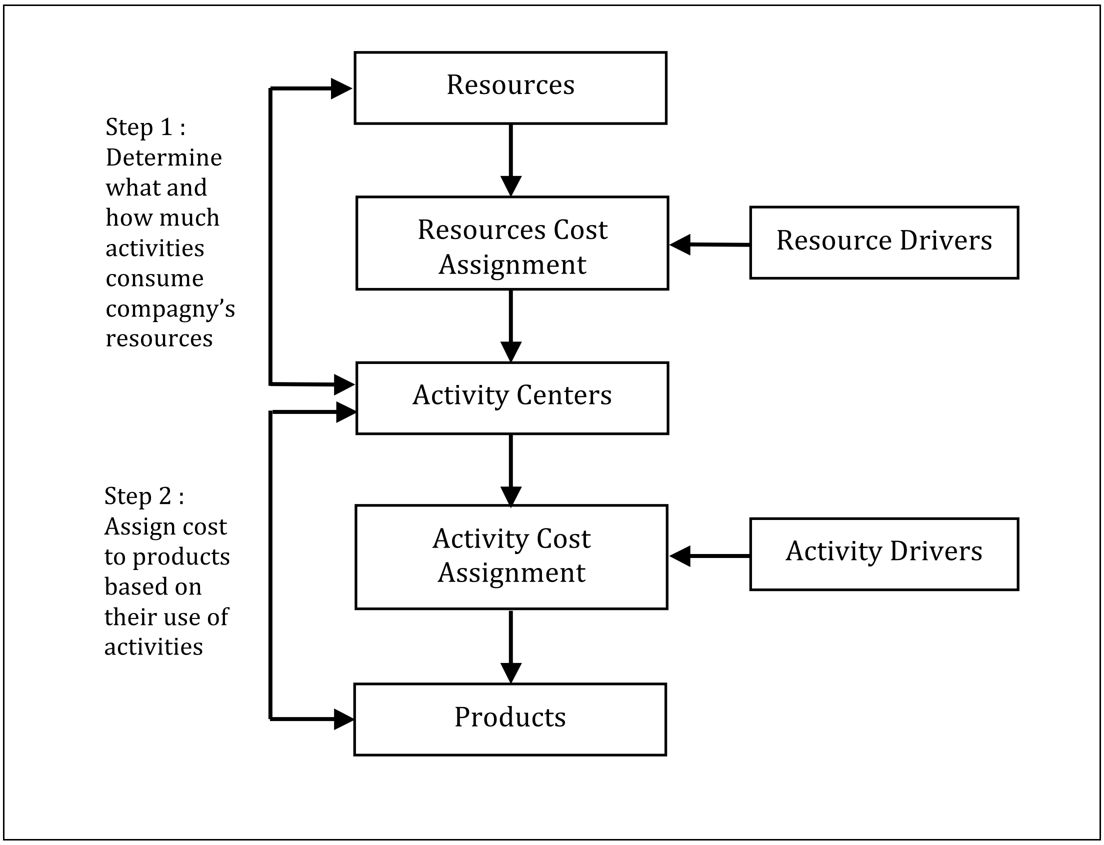

Figure 36: Two-stage cost Assignment to Products in ABC Systems (Park, 1995, p.440)

The difference between ABC and the traditional accounting system is the accurate allocation of the overhead costs. The traditional system allocates the overhead costs as a percentage of machine hours or direct labour hours, which is not exact. If the volume of the product increase by 8%, the manufacturing overhead costs increase equally. This assumption states that the machine hours or direct labour hours should increase proportionately. While this technique is easy and fast, it does not give actual and accurate costs of the product (Ong, 1995, p.162). In fact, the traditional cost accounting approach has been developed for mass production. So at the time of its development, the material costs were the highest costs of a product. Companies did not manufacture several different products, for these reasons it was not necessary to accurately assign overhead costs (Park, 1995, p.439). ABC has a two-stage assignment, as it is illustrated in figure 36.

ABC assigns all resources like suppliers, depreciation, direct labour and utilities of products to show the organisation operation. In the first stage, all the costs are assigned to activity centres. This does not differ from traditional cost accounting. Moreover, the second stage truly characterizes the advantages of an ABC system and separates it from the traditional costs system. As mentioned before, the ABC system realizes that many costs are not directly proportional to the produced items. In fact, many costs are directly proportional to the number of batches, which are produced. Furthermore, activity centres can be divided into two different homogenous processes like, machining processes:

- Punch press
- Machining
- Assembling

or business processes like:

- Distribution
- Marketing
- Procurement

In both cases, the activity centres are directly consumed by an item. For example, a part that is produced in a punch press operation consumes machining time and an operator.

The second stage drivers are used to assign the activity centres to the product with the right amount. These cost centres could be:

- Machine hours
- Direct labor hours

- Number of setups
- Inspections
- Setup time
- Warehouse moves

The second cost drivers give a clear picture of how the activity centres are consumed by products. Activity centres are composed of cost pools.

It is in regards to the previous example of the punch press, which will have two cost pools. The first cost pool represents production costs, like machine and direct labour costs. These costs are directly consumed by the production of the item and dependently from the required volume. This activity centre allocates these volume costs with the help of the number of machine hours, which are required for the product. On the other hand, the second cost pool contains the switch from one product to another. This includes moving material, setting up the machine, and inspection of the first produced item. In this case, the cost driver of machine hours would be pointless; hence the measurement of these two cost drivers is on different levels. In this specific case, the activity center has two-second stage drivers (Activity drivers): number of setups and machine hours (O'Guin, 1991, pp.41-43).

5.2.1 Cost occurrences in Activity Based Costing

The most significant difference between ABC and traditional cost is that the costs are hierarchical in an ABC system. Costs occur in different levels. Units, batches, products or facility levels are possible areas of incurrence. The ABC approach assigns some costs directly to the part, while, for example, the design engineering cannot be on the same unit level and instead it will be attached to a higher level. If the costs are directly related to the production volume, then that means these are unit costs. This could include direct labour, electricity, or tooling. On the other hand, inspection or set up activities take place in the batch level. Product driven activities (Ong, 1995, p.163; O'Guin, 1991, p.44):

- **Unit level**: The production costs are directly assigned to each unit. An example of this level would be placing a component on the product or drilling a hole (Ong, 1995, p.163; O'Guin, 1991, p.44).
- **Batch level**: the Manufacturing costs, which are allocated once for each batch. An example would be moving the batch from one process

to the other one or setting up a machine (Ong, 1995, p.163; O'Guin, 1991, p.44).

- **Product level**: which assumes that inputs for the production line are necessary. The maintenance costs or supporting costs to keep the line running are an example of product level (Ong, 1995, p.163; O'Guin, 1991, p.44).
- **Facility level**: the facility costs of a general manufacturing process sustained by this cost level. A general example could be administration costs, which cannot be assigned directly to one product if the factory is producing more than one product (Ong, 1995, p.164; O'Guin, 1991, p.44).

The first three costs (unit-, batch-, and product-level costs) are direct costs that can be allocated directly to one particular item. The last cost base, facility-level cost, includes common cost, which can be incurred from a variety of products. The estimation and allocation of it is more difficult than the other three level costs. ABC is considered to be a detailed and accurate cost estimation approach. ABC also shows the real costs of a product but in reality only the facility level costs assigned to different items are arbitrary (Ong, 1995, pp.162-163; O'Guin, 1991, p.44).
Finally, in order to calculate the unit cost, the obtained batch level costs must be divided by the batch size and the product level costs by the product life volume (Ong, 1995, p.163).

5.2.2 An Activity Based Costing methodology

As mentioned before, the early estimation of product costs is essential in a competitive environment. In order to reach the goal, the production stages of interest are the design and development phases. The design and development phases contain all activities, starting with the customer requirements, the design, process planning; and it ends with the production of a prototype (Ben-Arieh and Qian, 2002, p.806). The proposed ABC methodology steps from Ben-Arieh and Qian (2002, p.808) are demonstrated:

1. Identify the resource centres used;
2. Identify indirect costs and calculate their cost drivers;
3. Assign resources to each cost center and determine cost center driver rates;

4. Identify the activities that participate;
5. Analyse each activity and find the total cost for each activity;
6. Define activity drivers for each activity and find activity cost-driver rate;
7. Calculate the overall process costs based on the activities performed.

5.2.3 Implementation of the Activity Based Costing approach

Ben-Arieh and Qian (2002, p.808) adapted in their research the ABC implementation from Cooper and Kaplan (1999), which can be seen in figure 37. The modified implementation follows these steps:

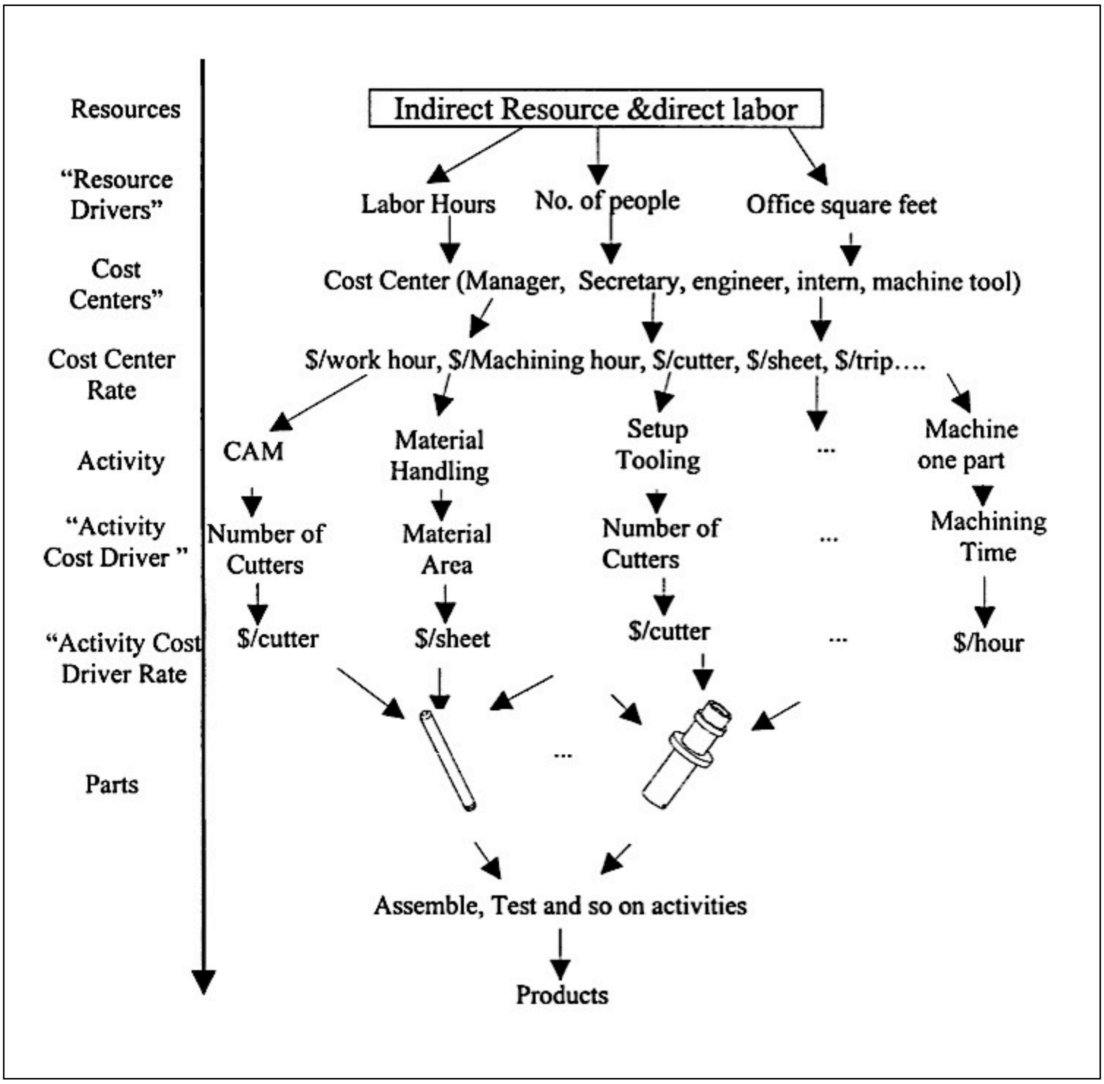

Figure 37: ABC implementation: Flow of expenses from resources to activities to products (Ben-Arieh and Qian, 2002, p.173)

1. Identify the resource centers used: The first step is to identify the cost centres within the company. These use the resources directly which are needed to produce the end item. Cost centres can be grouped in functional or economic homogeneous processes. A product driven cost centre allocates the costs of manufacturing and designing of the items. These costs contain production planning, engineering, quality control, warehousing, procurement, etc. Cost centres could also include human resources and major equipment. Manufacturing cells also provide a good opportunity to be a cost centre as the cell is a homogeneous process (milling machine centre, laser cutting centre, tooling centre) (O'Guin, 1991, pp.85-87).

2. Identify indirect costs and calculate their cost drivers: Indirect costs are all the overhead costs and need to be assigned to the end product. As the name indicates, direct labour and direct material costs can be directly traced from a product; and overhead costs are all the related costs to manufacture items. These costs need to be divided up and assigned to each unit item, which includes the expenses that come from cleaning, rent, heating, paper, water, software, etc. If we take an example like heating, the resource cost driver would be the square footage, while on the other hand the maintenance for computers is assigned by number of working hours. The following step shows the calculation for a resource cost driver, like the total costs in one year of the resource divided by the total amount of cost drivers consumed in one year (Ben-Arieh and Qian, 2002, p.172):

Equation 6: Resource rate (Ben-Arieh and Qian, 2002, p.172)

$$RR\ (Resource\ Rate) = \frac{Total\ costs\ for\ 1\ year}{Resource\ drivers\ spent\ in\ 1\ year\ (RD)}$$

3. Assign resources to each cost centre and determine cost centre driver rates: This step assigns the indirect resources to the cost centres, such as material handling, design engineering, or CNC turning center, which is based on the resource cost driver. This step also includes the calculation of the total costs of a cost centre. It is necessary to identify

one cost driver for each cost pool. For example, machining time is the cost driver for a machining centre, while number of trips is the cost driver for material handling. At the end of this step, one driver rate is calculated for each cost pool. Finally, in this step, the total annual cost can be calculated for one cost centre by the given equation:

Equation 7: The total annual costs for cost centers (Ben-Arieh and Qian, 2002, p.172)

$$Total\ annual\ cost\ for\ cost\ centre = \sum_{i=1}^{number\ of\ resources} RR \times RD$$

Whereby Resource Driver (RD) is the amount of how often resources spend at the cost centre in one year.

Equation 8: The cost centre rate (Ben-Arieh and Qian, 2002, p.172)

$$CCR\ (Cost\ Centre\ Rate) = \frac{Annual\ cost\ of\ centre}{Cost\ centre\ drivers\ spent\ in\ 1\ year\ (CCD)}$$

4. Identify activities: The fourth step of Cooper and Kaplan’s ABC implementation approach deals with the identification of activities. In a manufacturing environment plenty of activities can be defined to produce a finished product from raw materials. To model all of these activities in detail is very difficult and for that reason the consumption of some can be described in activity centres. For example, activities could be things, such as material handling, setup tooling, or a machine part (Özbayrak, 2004, pp.51-52; Ben-Arieh and Qian, 2002, p.807).

5. Analyse each activity and find the total cost for each activity: Based on cost centre resources dedicated to their respective activity, the costs for each individual activity are determined. This is done by multiplying the cost centre drivers rate by the amount of drivers that are used by each activity (Özbayrak, 2004, pp.51-52).

6. Define activity drivers for each activity and find activity cost-driver rate: An activity cost driver is a specific factor in explaining the cost incurrence by one activity. In most cases, ABC uses different types of cost drivers, such as duration drivers or transaction drivers. The former describes how long it takes to perform this activity and the latter explains the number of times an activity is processed. Sometimes it is quite easy to find appropriate cost drivers, such as machine hours, which correspond to the costs of a machine while performing an activity. However, some cost drivers are hard to categorise. In this case, an innovative definition has to be established. ACDR is the Activity Cost Driver Rate, which can be obtained by taking the total costs of one activity divided by the value of the activity cost driver (Özbayrak, 2004, pp.51-52).

Equation 9: Activity cost driver rate (Özbayrak, 2004, p.51)

$$ACDR = \frac{Cost\ of\ one\ activity}{Activity\ cost\ driver\ spent}$$

$$= \frac{\sum_{i=1}^{number\ of\ cost\ centres\ used}(CCR_i \times CCD_i)}{ACD}$$

CCD_i	amount of the driver of centre used for activities
ACD	amount of the activity cost drivers

7. Calculate the overall process costs based on the activities performed: Finally, the total costs of one item can be calculated, with each product being defined by their consumed activities and the value of their cost drivers (Ben-Arieh and Qian, 2002, p.807).

Equation 10: Total costs of one part (Ben-Arieh and Qian, 2002, p.807)

$$Total\ costs\ of\ one\ part = \sum_{i=1}^{number\ of\ activities} (ACD_i \times ACDR_i)$$

To understand the characteristics and to become familiar with ABC, a principle picture is presented which compares ABC and traditional cost analysis (figure 38).

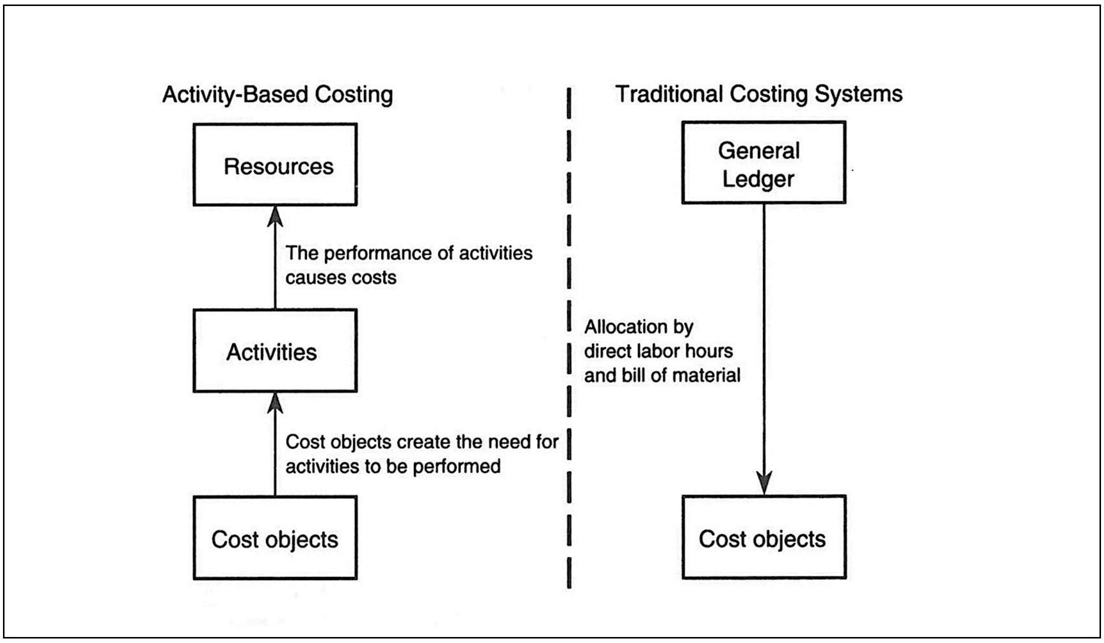

Figure 38: Main principles of ABC and traditional costing system (Emblemsvåg, 2003, p.106)

5.3 Conclusion

This section provides a detailed description of ABC and CBR along with all the necessary knowledge of how a database works within a CBR method and how it could be linked to an ABC method. ABC has been described in seven different points on a level, which will be used for the case study (section 6). Unfortunately CBR is described in a conceptual way and is not yet ready to be implemented completely but conceptually it works perfectly.

6 Practical approach by using the aforementioned methodology in a real case and within Windchill

The methodology that has been developed will be applied to a case to estimate the manufacturing costs. The product is a pulley. In more detail, the analysis describes the costs of designing, developing and manufacturing the pulley described in figure 39.

6.1 Formulation of the case study

The main purpose of this case study is to show the implementation of the developed approach in an existing case. For confidential reasons, all the costs are fictive.
There are also possible implementations of the methodology in a well-established program called Windchill. Windchill is a program developed by PTC, who also developed ProEngineer. It is Manufacturing Process Management and Product Data Management software in one.

Description
The first part of this chapter will explain the use of a pulley and the different components from which it is assembled. To be able to do a cost analysis the information from the Manufacturing Process Management of the capacity of the manufacturing machines is necessary to illustrate a shop floor process and to calculate all the corresponding overhead costs in order to assign them accurately to the products. After that, the implementation of the methodology is provided and explained. The absence of any important data makes a CBR analysis useless, as was the situation for this case. So, a conceptual explanation of CBR takes place. However, ABC was used to obtain a detailed solution, where the methodology concludes with a suitable end result.

The work procedure, which an MPM engineer has to follow, is roughly explained in the following sentence.
The first part is to define all the processes in Windchill and finish the common tasks in this MPM software, such as the required basic data and process plans. After this step, the implementation of the methodology to estimate the cost in the early product development stage can be done.

6.2 The pulley for sailboats

Definition

"A pulley is a wheel on an axel that is designed to support movement of a cable or belt along its circumference" (Wikipedia, 2012). It is used to transmit forces and lift loads.

6.2.1 The purpose of a sailboat pulley

In my case, the pulley is used for sailboats, so the required function is to transmit forces. Actually, the company produces several different kinds of pulleys to use in proximity to (salt) water.

My focus will be on three different pulleys that show the capability of the methodology, especially for ABC. If the costs only need to be estimated for one product, then the situation would be easy but this is never the case in industry; companies usually produce more than just one product. Secondly, I would like to show how accurately the overhead costs are allocated to each product or item. It is possible to apply this method to one product; but as said before, the ABC can work with several different items or products. It would be pointless to determine all the different overhead costs in detail if only one product is responsible for their occurrence.

The three individual types of pulleys differ only in the size and in the modification of the flanges. Product one is the high-end pulley with the most possible modification and product three is the standard pulley. Product two is in the middle of these. The annual output production is estimated to 5000 units, 2000 units, and 3000 units respectively 1,2 and 3. The differences between the products are illustrated in table 1.

Table 1: Different products oft he pulley

Products	Modification	Annual production
Product 1	high	5000
Product 2	middle	2000
Product 3 (standard pulley)	low	3000

6.2.2 Description of the standard pulley

Figure 39 illustrates the standard pulley with a top-, front- and side view. It is assembled in total, with three main parts. It is made up of two flanges, which are marked in figure 39 with a (1), of one or more bearings (2) which are placed in the middle of the two flanges, of fastening and of different accessories. This could be, for example, a jam cleat. The flange can be manufactured in many different ways, for several varieties of use. Such different (3) possibilities include opening and fixing it to the needed places. Furthermore, beckets (5) support the user with guides for the rail end.

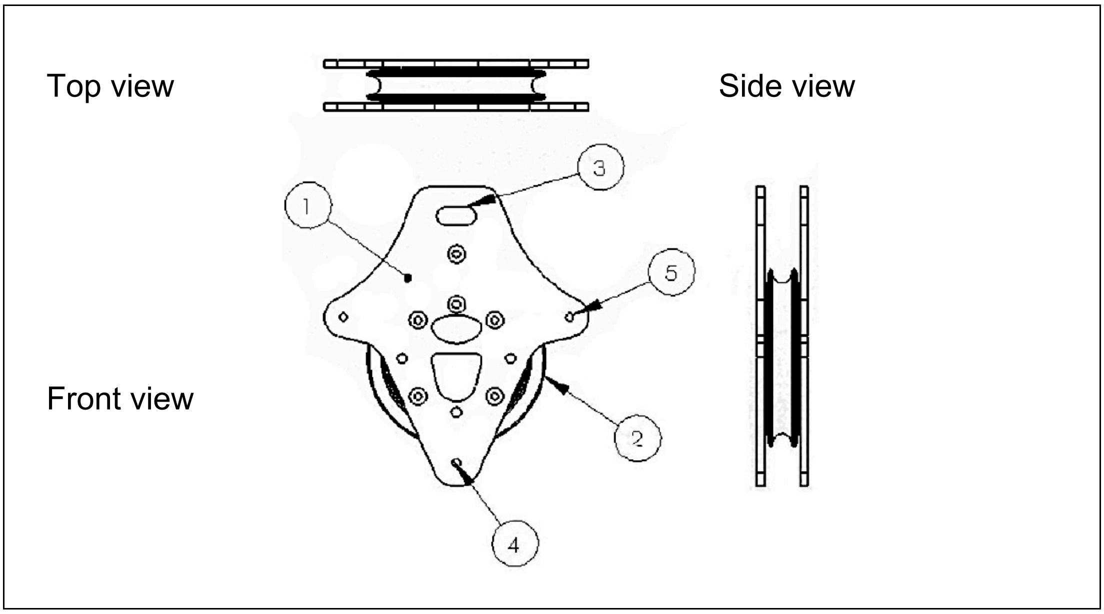

Figure 39: Description of a pulley (Le Duigou, Bernard, Perry and Delplave, 2010, p.6)

6.2.3 Manufacturing process of the pulley

Different kinds of processes are applied to manufacture the pulley. The bearing in the middle is purchased and the flanges are produced completely by the company. The assembling process takes place in the factory as well.

Flanges

The material used to make the flanges is a composite carbon material that is produced by the employees within the company. This material has been chosen because it is ultra light, strong, and its excellent resistance against saltwater. The employees produce the composite carbon blocks by hand. After combining the carbon and the epoxy in many layers, the polymerisation

can start. The process is called compression molding. It is a quick method that uses a compression mold. It is a two-piece mold (consisting of male and female components). The composite material is placed between the two molds. The molds are then closed with a specific temperature, amount of time and pressure in order to produce the carbon composite block.
After that the specific shape of the flanges is manufactured on a vertical milling center. The holes and grooves are done with a drilling machine.

Assembly
Finally, all three main parts are manually assembled at an assembly station. The corresponding eBom for the pulley can be seen in Figure 40.

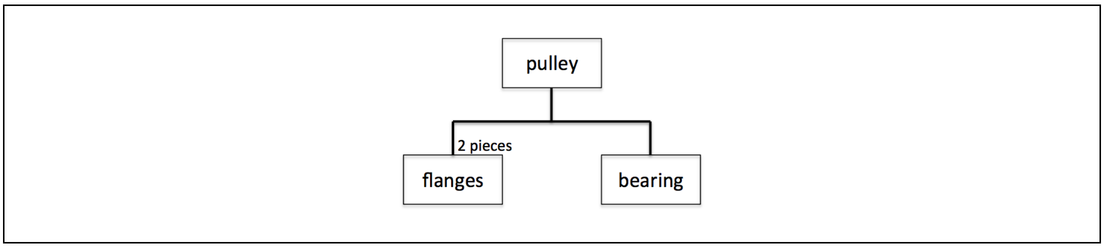

Figure 40: eBOM of the pulley

6.2.4 Layout of the shop floor

The shop floor and the process flow are configured as illustrated in figure 41. It starts with an area for receiving the individual parts and the raw material. After that, the processes that are needed to manufacture one product follow. Each of the milling and drilling stations consist of three machines. After passing through all five stations, the shipping area is the final storage area before the products get shipped.

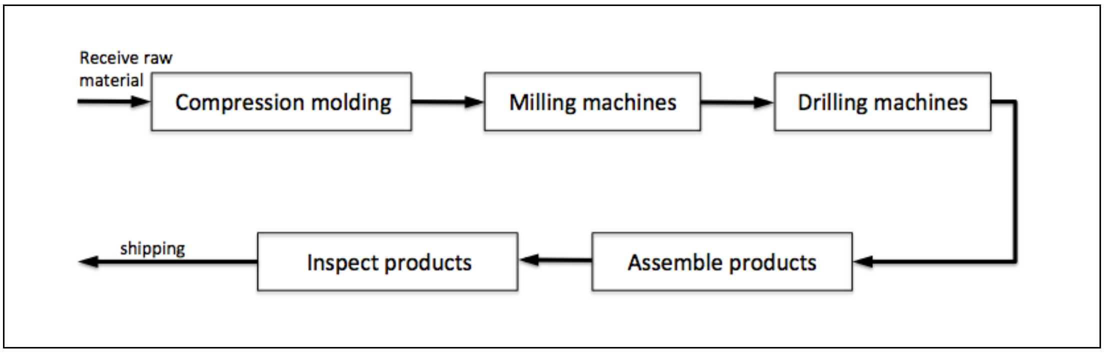

Figure 41: Shop floor layout

6.3 Applying the Methodology for Early Cost Estimation

After the introduction and definition of the case, the previously proposed cost estimation approach will be applied. As mentioned before, it consists of four steps.

6.3.1 STEP 1: Product and resource influence

In order to achieve a suitable end result, the necessary data for this approach needs to be obtained by a careful search. All the accurate information that could help should be taken into consideration. Unfortunately, in the early development phases it is harder to obtain accurate information. To be able to achieve the best possible result, the search for information is a vital step.

The pertinent information has already been given and explained (item data, bill of material data, routing data and work center data).
However, the product needs to be broken down so that the next steps can have a discussion about the individual items of the product. In fact, only the flanges get manufactured and in the assembly station all the different items meet again to be assembled into a pulley.

6.3.2 STEP 2: Establish the right cost estimation approach

Step two requires a decision from either Case Based Reasoning or Activity Based Costing; fortunately, this decision will be supported by the methodology. If a similar case cannot be found in the database then it will go on to calculate the costs with the help of Activity Based Costing, which is more time consuming than finding a case that is close to the item and then plots the result. Each item is checked separately whether similar parts already exist or not.
The methodology starts with Case Based reasoning.

According to the case, the pulleys could not be found in the database which means the costs has to be estimated with ABC and will follow in the next section.

Case Based Reasoning
The concept of Case Based Reasoning applied in the manufacturing industry is very simple and easy to understand but the use of it requires several tools

and a well maintained database that allows searching and the saving of cases. However, this database has not been provided. Moreover, to identify the similarities, special programs/tools are required which work, for example, with the comparison of step-files to identify the degree of equality (El-Mehalawi and Miller, 2003, p.85). However, the conceptual use of CBR is in the following section, without a significant focus on the pulley. Figure 42 illustrates the conceptual use of CBR with a special focus on CAD models and of MPM. The total manufacturing costs of the source models are known and the aim is to estimate the total manufacturing cost from the source model, with the help of similarities between the cases.

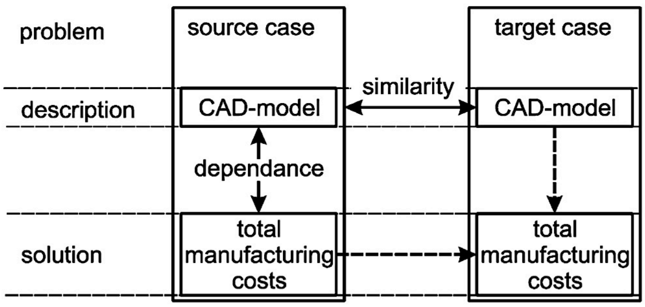

Figure 42: Principle of working of case-based reasoning (Ficko, et al., 2005, p.1330)

To be able to find the most similar model, CBR has to follow four basic steps: (Ficko, et al., 2005, p.1330)

- Collect the technological and geometrical information from the computer database
- Extract the geometrical features from the most similar case (target case)
- Select the most similar cases (source cases from the database)
- Propose the result of the target case or cases.

As mentioned in the theoretical part of this work (Section 5.1), the database is the heart of this approach, which means that the source cases are needed to be able to use CBR. Therefore, the technological and geometrical information has to be collected within an enterprise.

However, figure 43 illustrates a flow diagram of the case based approach. The dotted lines indicate the cost interface to the system. The flow down diagram starts with the new outlining of a product design specification (Niazi, et al., 2006, p.564).

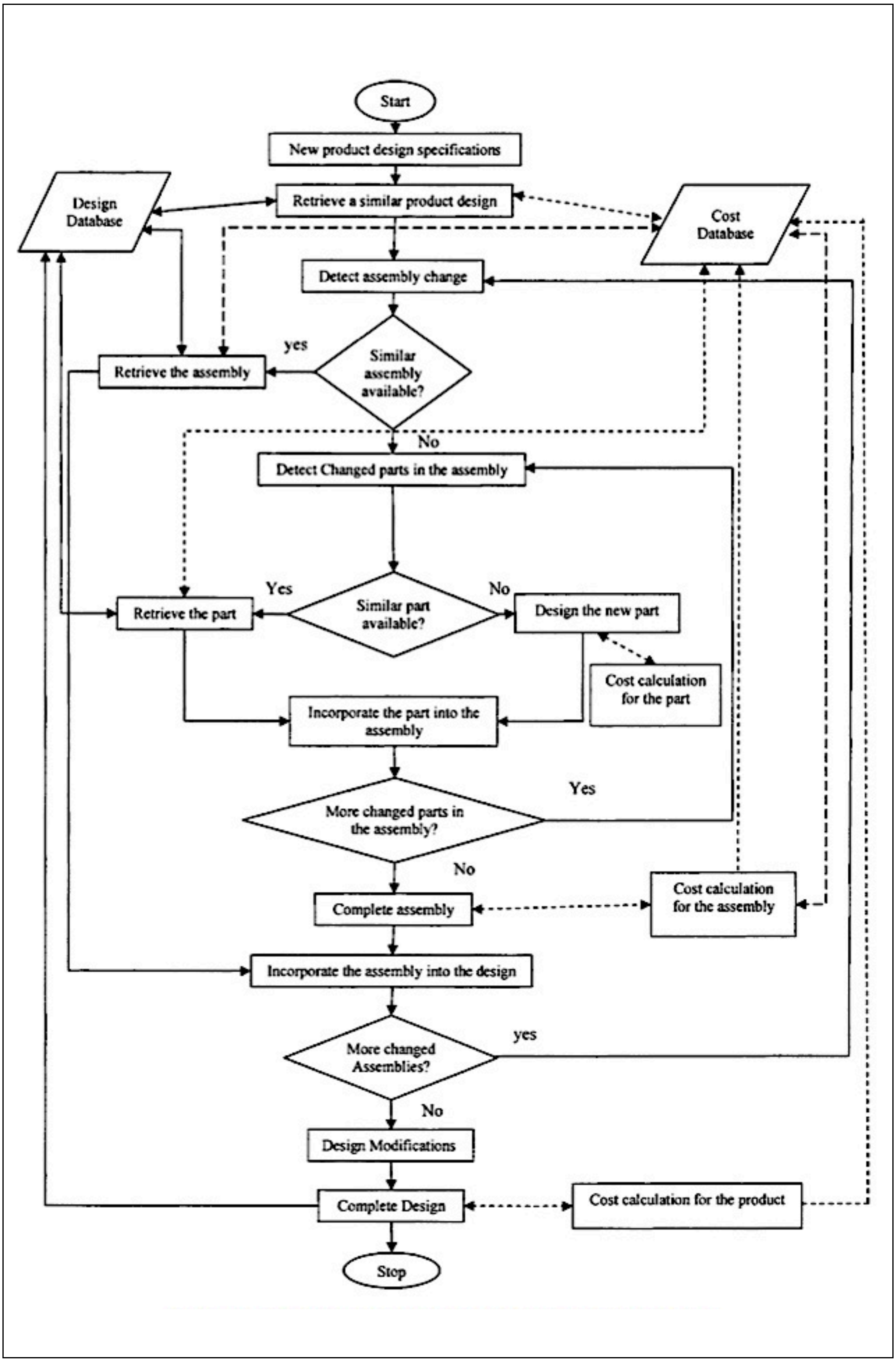

Figure 43: Flow diagram of Case Based Reasoning (Niazi, et al., 2006, p.565)

Activity Based Costing

ABC is a detailed cost estimation approach, which will be applied to the case because it is part of the methodology. Three pulleys are produced in one factory; this situation is the best way to show how ABC is accurately allocating all the overhead costs for the individual products. It would be senseless to allocate overhead costs to one product, because all costs occur for this product.

Figure 44 shows a schematic flow diagram of how the costs are assigned and how the case will be solved in ABC. The direct costs are directly separated and assigned to the bill of material and in the end they can easily be added to the product costs.

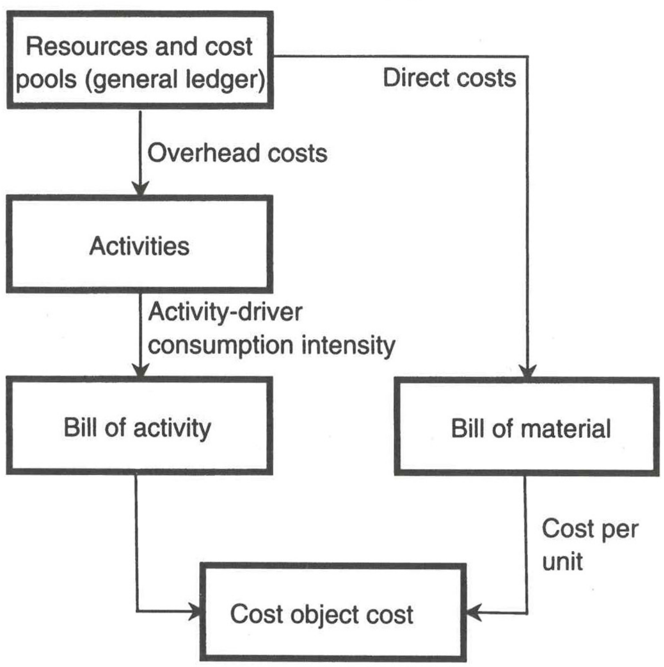

Figure 44: ABC cost assignment overview (Emblemsvåg, 2003, p.106)

The strength of ABC is being able to assign the overhead costs accurately. This means that everything that a product consumes in overhead costs will be assigned to this product. To achieve that, ABC is made up of two steps (figure 36). Step one deals with allocating how many activities the product is consuming and step two focuses on how many activities are consuming the company's resources.

The illustrated case study about the sailboat pulley follows the steps of figure 44. Table 2 illustrates the hourly labor costs of the workers and table 3 presents a summary of direct costs and the annual costs of the products. These direct costs are illustrated as BOM costs.

Table 2: Labor Costs

Labors	Labor cost (€/h)
Molding operator	5,80
Mill operator	6,90
Drill operator	6,60
Assembler	5,90
Inspector	8,40
TOTAL	33,60

Table 3: Summary of BOM costs

Products	Unit Cost (BOM)	UNITS	Annual Costs
P1	60,3	5.000	301.500
P2	26,8	3.000	80.400
P3	37,06	2.000	74.120
TOTAL			456.020

ABC implementation

After clarifying and collecting the basic required data that allows for an ABC analysis, the implementation of the ABC system can be started. This section will show a way to implement ABC within the methodology. It consists of seven main steps; some of them can be performed at the same time:

1. Categorize all the collected cost data
2. Determine a Bill of Activities (BOA)
3. Define Resource drivers
4. Calculate Activity costs
5. Define Activity driver and collect data
6. Determine cost pools (these pools consist of a summation of the same cost drivers to provide an easier calculation)
7. Calculate the product or customer costs

The customer perspective has to be taken into consideration because sometimes costs are not driven by product characteristics but instead by customers. Customers determine some costs, so for that reason it is an important factor. For example, the costs for invoices, which occur after everything is finished, are sent to customers and not to the products. That means that they are assigned for customers and not according to products (Emblemsvåg, 2003, p.130)

Categorisation of all the collected cost data

Table 4 presents all the costs, which will be incurred over the next 12 months, according to previous years of experience at the factory or based on the estimator's knowledge.

Actually, the BOM costs are also included but these costs are declared as direct costs, for that reason they will be excluded from the next steps. At the end of the ABC calculation, these costs are always directly added and influence the price of the end product.

4: Costs of the company

Cost Categories	Costs (€/year)	Cost Categories	Costs (€/year)
Building	255.000	BOM	456.020
Conveyer system	5.100	Support equipment	9.900
Compression molding machine	14.000	Indirect labor	1.092.450
Milling machines	20.000	Office equipment	34.900
Drilling machines	16.000	Inspection equipment	590
Assembly equipment	1.040		
TOTAL			1.905.000,00

Table 4 also shows the total annual costs of the enterprise, which are 1.9 million euros. It also shows that it is a small enterprise. It can be seen that the costs of the building are quite high and may seem too expensive. However, all these points are not particular to this ABC analysis; it should only show that ABC is a high decision making, cost allocating, and cost determining tool which allows questions to be asked, by working with all cost data.

Determine a Bill of Activities (BOA)

The purpose of this step is to allocate all working time from the indirect workers/employees so that afterwards it can be traced back to activities. This step requires previous knowledge or good estimators to distribute the labour costs to the activities.

Usually this is done by holding interviews and design questionnaires for finding the distribution key. In this case it is not possible to do this as the product is not yet in a manufacturing process.
Table 5 illustrates a sample of the activities during the production of three products. The percentages may seem odd but they come from conversions.

Table 5: Activity time in percentage

ID	Activity Name	Time Percentage
A1	Receive parts	1,2%
A2	Run inventory	0,5%
A3	Ship products	1,2%
A4	Run Compression molding	15,7%
A5	Run milling	15,4%
A6	Run drilling + deburring	9,3%
A7	Assemble products	12,1%
A8	Inspect products	11,1%
A9	Design products	4,2%
A10	Market/sell products	4,2%
A11	Service customers	3,2%
A12	Maintain facility	1,2%
A13	Lead Company	2,5%
A14	Run production	7,1%
A15	Process orders	4,2%
A16	Manage costs	6,9%
TOTAL		100,0%

Define Resource drivers

Resource drivers are used to allocate the resources (under cost categories from table 4) to activities, which is step one in an ABC analysis (figure 36). Table 6 presents three different resource drivers, such as labour hours, area, and stations. The area resource driver is logical and well understood. For example, if an activity uses more space in the factory, then this activity will consume more resources, so the justification of this driver is proven. The second one works only for indirect labor costs and concerning the third one; it is distributed equally among the activities A4 to A8. The reason for this is that they are all connected in the process flow via the conveyer. It is important that too many allocations are not added, as it is more confusing than beneficial to the ABC model.

The strongest relationship is the direct allocation between activities and resources such as milling, drilling and molding machines. It is a one-to-one relationship. For example, the compression-molding machine has a one to one relationship with A4. If this is the case, it is the best situation that can occur because the distortion goes to zero.
Please note that table 6 excludes the direct costs of the BOM, so they will simply be included in the end of the ABC analysis.

Table 6: Resource Driver definitions

Cost Categories	Costs (€/year)	Name of the resource drivers
Building	255.000	Area
Conveyer system	5.100	5 stations
Compression molding machine	14.000	Direct
Milling machines	20.000	Direct
Drilling machines	16.000	Direct
Assembly equipment	1.040	Direct
Support equipment	9.900	Labour hours
Indirect labour	1.092.450	Labour hours
Office equipment	34.900	Labour hours
Inspection equipment	590	Direct
TOTAL	1.448.980	

Calculate Activity Costs

With these resource drivers and the data that is shown in table 6, it is possible to calculate the costs of each activity. The results are shown in the bottom line. Table 7 illustrates exemplarily how to calculate these costs for activity 5 and 16. A summation of all the activities is provided in table 8. Furthermore these results can be illustrated in a graph, as shown in figure 44. This graph is a support tool for identifying abnormal process costs or the possible identification of important activities to either reduce the costs or eliminate them. Moreover, the areas of waste can be seen. With this graph the MPM engineer can rethink all the steps to determine whether or not the result is suitable.
In fact, the graph shows that the highest overhead costs are part of the core production of the product (A4-A8).

Table 7: Example of BOA costs

Cost Categories	Costs (€/year)	Name of the resource drivers	Total [%],[m^2]	Consumtion intensity	Resource Driver (A5)	Activity cost of A5 [€]	Resource Driver (A16)	Activity cost of A16 [€]
Buliding	255.000	Area	16550 m^2	15,41 €/m^2	1000	15.408	100	1541
Conveyer system	5.100	5 stations	5	1020 €	1	1.020		0
Compression molding machine	14.000	Direct	100%	14000 €		0		0
Milling machines	20.000	Direct	100%	20000 €	1	20.000		0
Drilling machines	16.000	Direct	100%	16000 €		0		0
Assembly equipment	1.040	Direct	100%	1040 €		0		0
Support equipment	9.900	Labor hours	100%	9900 €	15,4%	1.525	6,9%	683
Indirect labor	1.092.450	Labor hours	100%	1092450 €	15,4%	168.237	6,9%	75379
Office equipment	34.900	Labor hours	100%	34900 €	15,4%	5.375	6,9%	2408
Inspection equipment	590	Direct	100%	590 €		0		0
TOTAL [€]	1.448.980					211.564		80.011

Table 8: Bill of Activities (Cost of each Activity)

Activities	Cost	Unit	Percentage
A1	20.272	(€/year)	1,4
A2	159.765	(€/year)	11,0
A3	20.272	(€/year)	1,4
A4	208.309	(€/year)	14,4
A5	211.564	(€/year)	14,6
A6	142.500	(€/year)	9,8
A7	155.902	(€/year)	10,8
A8	142.790	(€/year)	9,9
A9	48.843	(€/year)	3,4
A10	48.843	(€/year)	3,4
A11	36.392	(€/year)	2,5
A12	15.496	(€/year)	1,1
A13	28.739	(€/year)	2,0
A14	81.515	(€/year)	5,6
A15	47.765	(€/year)	3,3
A16	80.011	(€/year)	5,5
TOTAL	1.448.980		100,0

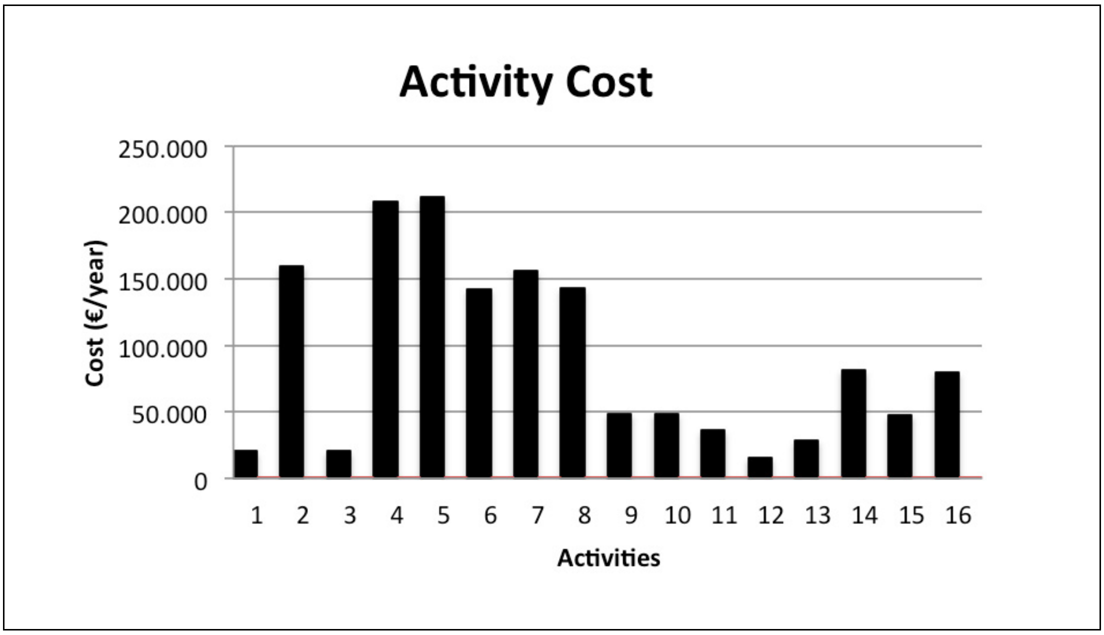

Figure 45: Activity cost

Define Activity driver and collect data (STEP two of ABC)

This is step two of an ABC analysis, corresponding to figure 36. The definition of the activity drivers is necessary for distributing the activities to the products with an accurate rate. Through traditional cost estimation the activities do not exist; the overhead costs are directly assigned to the products. Table 9 illustrates ten different kinds of activity drivers. For example, annual production is used for five different activities, namely, A3, A8, A10, A12, and A13. One of the important parts is to choose activity drivers according to the information, which could be collected or which is available in the enterprise. The different activity drivers are also justified because costs do not appear at same levels, compare with section 5.2.1 (unit, batch, product, and facility levels). The most accurate activity drivers are all the ones that are consumed directly by the product, such as molding labour hours, drill labour hours and assembly labour hours. The reason for this is that in the manufacturing process, mainly workers are keeping the process flow, without any usage of automation. To provide an easier analysis of those activity drivers, which are the same, they can be added in a so-called activity pools. These pools always consist of the summation of all the same activity drivers. This is executed in the following step.

9: Activity driver definitions

ID/ Activity	Activity Driver	Cost (€/year)
A1	Annual component use	20.272,4
A2	Annual component use	159.764,8
A3	Annual production	20.272,4
A4	Molding labour hours	208.309,3
A5	Mill labour hours	211.564,4
A6	Drill labour hours	142.500,3
A7	Assembly labour hours	155.902,1
A8	Annual production	142.790,4
A9	Number of products	48.843,0
A10	Annual production	48.843,0
A11	Number of inquiries	36.392,0
A12	Annual production	15.495,9
A13	Annual production	28.739,4
A14	Number of batches	81.515,1
A15	Number of orders	47.764,5
A16	Direct labor hours	80.011,0
TOTAL		1.448.980,0

Create Cost Pools

Cost pools can be created, based on table 9. The advantage of creating these pools is to reduce the complications of the ABC model. Unfortunately it could reduce the accuracy of the model but in contrast, it reduces work time. It is important to say, that a balance must be found between costs and useful details.

Table 10: Definition of Cost Pools

Activity driver	Cost Pools (€/year)	Activity driver	Cost Pools (€/year)
Annual component use	180.037,2	Molding labour hours	208.309,3
Annual production	256.141,1	Number of inquiries	36.392,0
Mill labour hours	211.564,4	Number of batches	81.515,1
Lathe labour hours	142.500,3	Number of orders	47.764,5
Assembly labour hours	155.902,1	Direct labour hours	80.011,0
Number of products	48.843,0		
TOTAL			1.448.980,0

Calculate product costs

The final step of the product cost calculation supported by ABC is to relate each cost pool to each product by using the activity drivers as illustrated in table 10. For example, if we pick out the cost pool and annual component use, then in total it consumes 180.037,20 Euros per 98000 components each year, for all the products. However, each product consumes a different amount of components each year. Product one consumes 60.000 components a year, which is the largest user; moreover product 2 and product 3 are consuming 20.000 and 18.000 components annually. These three different values are used to calculate the corresponding annual costs according to the consumed activities for each product. An exemplary calculation is provided below:

Equation 11: Product costs of the different pulleys

$$\boldsymbol{Product\ 1\ (annual\ component\ use) = 180.037,2 * \frac{60.000}{98.000} = 110.227€}$$

$$\boldsymbol{Product\ 2\ (annual\ component\ use) = 180.037,2 * \frac{20.000}{98.000} = 36.742€}$$

$$\boldsymbol{Product\ 3\ (annual\ component\ use) = 180.037,2 * \frac{18.000}{98.000} = 33.068€}$$

In this way, the calculation for the consumption of each cost pool by the products take place. After that, the summation of all the overhead costs gives a total amount for each product. Finally, the BOM costs have to be added and the total costs for each product per year are illustrated in the last row of table 11.

Table 11:Production cost calculation

Activity driver	Cost Pools (€/year)	Avtivity driver value	PRODUCT 1		PRODUCT 2		PRODUCT 3	
			Activity Driver	Cost	Activity Driver	Cost	Activity Driver	Cost
Annual component use	180.037,2	98.000	60.000 (components)	110.227	20.000 (components)	36.742	18.000 (components	33.068
Annual production	256.141,1	10.000	5.000 (#)	128.071	3.000 (#)	76.842	2.000 (#)	51.228
Mill labor hours	211.564,4	17.420	8.000 (h)	97.159	6.000 (h)	72.869	3.420 (h)	41.536
Drill labor hours	142.500,3	7.550	3.750 (h)	70.778	2.200 (h)	41.523	1.600 (h)	30.199
Assembly labor hours	155.902,1	13.451	8.751 (h)	101.427	2.600 (h)	30.135	2.100 (h)	24.340
Number of products	48.843,0	3	1 (produc)	16.281	1 (produc)	16.281	1 (produc)	16.281
Molding labor hours	208.309,3	15.745	7.045 (h)	93.207	5.500 (h)	72.766	3.200 (h)	42.337
Number of inquiries	36.392,0	5.400	2.000 (inquiries)	13.479	1.900 (inquiries)	12.805	1.500 (inquiries)	10.109
Number of batches	81.515,1	5.000	2.500 (batches)	40.758	1.500 (batches)	24.455	1.000 (batches)	16.303
Number of orders	47.764,5	2.700	1.200 (orders)	21.229	500 (orders)	8.845	1.000 (orders)	17.691
Direct labor hours	80.011,0	55.950	34.900 (h)	49.909	12.330 (h)	17.632	8.720 (h)	12.470
Total Overhead costs	1.448.980,0			742.523		410.896		295.560
Direct costs (BOM)	456.020			301.500		80.400		74.120
TOTAL COSTS	1.905.000,0			1.044.023		491.296		369.680

Result

The final result of this ABC analysis can be seen in table 12, the costs per items. Overhead costs and direct costs are exactly allocated to the products in a way in which they appear based on their consumption of resources.

Table 12: Product cost

Product	Production per year	Cost per item
Product 1	5000#	208,8 (€/#)
Product 2	3000#	163,8 (€/#)
Product 3	2000#	184,8 (€/#)

6.3.3 STEP 3: Comparison analysis

In step four, decisions have to be made on whether to outsource or stay in house. Figure 27 illustrates a support tool for deciding whether outsourcing should take place or not. In this case, it is a small company and all processes are core processes and the performance is good, so outsourcing is out of the question.

However, the ABC analysis can also be performed but only for individual items in order to determine if these items can be outsourced or not. In this case, it was pointless to perform the analysis for the individual items because the pulley only contains three main parts, two of which are purchased. If outsourcing was chosen, the factory would not have been used.

6.3.4 STEP 4: The improvement step

In this step all the calculated or collected cost data per item can be tested for improvement by making some design changes or reducing parts etc.

Especially in this case, the end results are suitable and the calculated costs are saved in the database for future products. With the saved parameters, the costs of similar future products can be easily determined with the help of Case Based Reasoning in the proposed methodology.

The results, which are obtained in this case study, confirm that the solution of the methodology meets the required needs and on top of that it proves that it functions well. It provides a well needed service.

6.4 Conclusion

This section provides a practical approach which uses the before described methodology. All four steps are explained in detail and the case proves that the framework works in real cases and not only in theory. However, the necessary data for a database was missing, so CBR is explained in a conceptual way.

7 Possible Implementation in Windchill

Windchill was developed from PTC and is an MPM and PDM software. Within this software, how to manufacture a product is discussed, process plans can be created and it supports companies in the development stages of products. This is because it can all be done at the same time. However, the advantages and disadvantages have already been explained in section 2, Manufacturing Process Management.
This section will shortly explain a possible implementation of the developed methodology in Windchill. Currently, Windchill does not provide accurate cost estimations of products, even though it presents a perfect plan for the manufacturing processes. Obviously, it is logical to add a supportive cost estimation tool to make decisions and justify them. In fact, one of the key elements for deciding whether or not to produce comes from the costs, which need to be taken into careful consideration. The methodology supports this. In addition, it helps to establish a feeling about the different costs, which arise from different processes. The MPM engineer will be able to combine the best processes to obtain the most accurate and best cost quality ratio for the products.

7.1 Basics of Windchill

Windchill consists of five MPM explorers, as can be seen in Figure 46:

- Product Structure explorer
- Manufacturing product structure explorer
- Manufacturing resource explorer
- Manufacturing Standards Explorer
- Process Plan explorer

Manufacturing product structure explorer
This explorer is used to create the mBOM using information from the eBOM. This is necessary to be able to allocate all processes, even for different workstations. The product structure is shown in the left of the pane and on the right, additional information can be found.

Manufacturing resource explorer
This explorer contains all the manufacturing resources that are needed to produce products such as skilled employees, factories, resource groups, machines etc.

Manufacturing Standards Explorer
This explorer is used to create manufacturing standards, such as standard procedures or standard groups, which should be used whenever possible.

Process Plan explorer
This explorer is used to create and manipulate process plans. A process plan describes, in a detailed step-by-step fashion, how a certain item has to be manufactured or how all items must be assembled to make a product. A process plan should be created according to the mBOM.

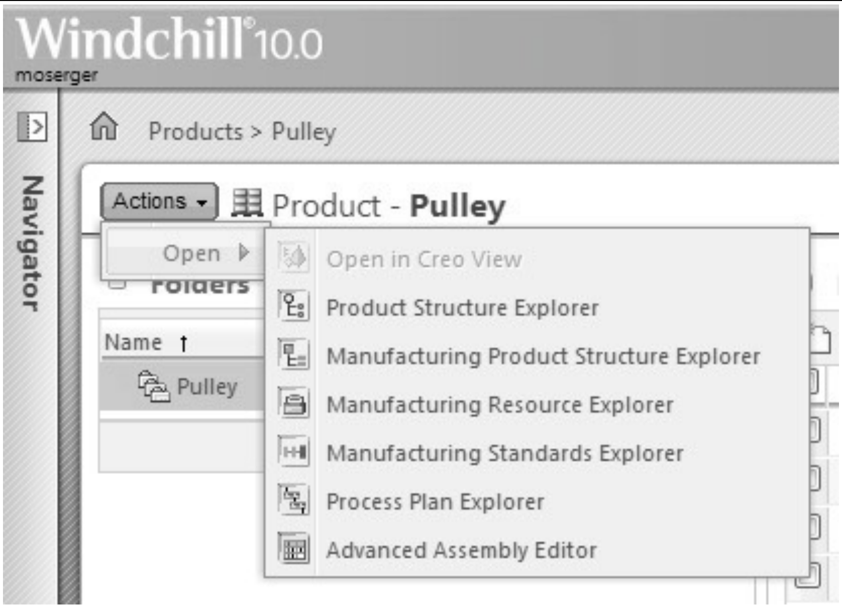

Figure 46: Windchill MPM and PDM link explorers

7.2 Implementation of the methodology in Windchill

Using the methodology developed within this thesis, a fifth explorer can be integrated into the Windchill program. It will deal with all the costs that occur when manufacturing a certain product. This button will take everything into consideration, which the methodology insists. Also, it has to be linked to an external database or the database from Windchill, so that it will be able to recommend the most similar case for case based reasoning and finally will be able to save all the generated information.

After finishing all the required planning steps in Windchill, the user can start to calculate the costs by pressing the cost explorer button. With this button, the proposed methodology is used. The four steps have to be processed by the user but Windchill MPMLink partly supports some of them.

7.2.1 STEP 1: Product and resource influence:

The tasks, which are necessary during step one, will already have been required in Windchill MPMLink. Step one requires item data, bill of material data, routing data and work center data, which was explained in more detail in section 4.5. All these data is required to obtain good process plans and with them, the production can start immediately. For this reason the data corresponding to the products is already given. However, the data for costs is not provided, which has to be done.
The database needs to provide all the overhead costs, which come from the inventory and employees, such as building, machine, depreciation, and indirect labour costs that coincide with table 4.
Usually, a company does not only produce one product. So in MPMLink, the factory and the capacity of the factory are given and for this reason, the overhead costs are well known. The BOM costs (direct costs), such as material costs can be easily estimated by inquiring at the suppliers.
However, it would be best if the company already had a good working cost estimation program that could be linked to Windchill MPMLink to obtain the necessary information or an already integrated one. If this is the case and it is used in conjunction with the ABC system, then it would best fit the methodology. The interaction between these two programs or one program with more tools can, in theory, bring competitive advantages, which are desired in industry.

7.2.2 STEP 2: Establish the right cost estimation approach

After the database is fed all this information, or has obtained it from the cost estimation program, which the company is using, then step 2 can start.
This step starts with an analysis of the 3D-CAD items and tries to find similar models in the database. If the database finds the required similar cases, the

costs can be directly plotted in the interface. If not, the program has to open a new window with an ABC analysis. This analysis would work in a way similar to the proposed case study. It would start by categorizing all the collected cost data and be followed like a red line, step by step, to determine the BOA, define resource centers, calculate the activity costs, define activity drivers, determine cost pools and finally come up with the costs of the item.
After reaching these costs, the costs explorer is used and the costs should appear for each item with the total costs of the product.

7.2.3 STEP 3: Comparison analysis

At first, the MPM engineer has to follow the decision tree from figure 26 for each part. If he decides it would be possible to outsource some of the part, then the program will suggest alternative possibilities, if the database contains any. A direct link to the suppliers is also of utmost importance in obtaining a good final end result. If by now, all the decisions are made and the end result of the items or product is fixed, the MPM engineer or manager will either be satisfied with the result or not. This is part of the following step.

7.2.4 STEP 4: The improvement step

The improvement step contains the last decision that must be made before the production can start. If all of the obtained results are satisfactory, then the manufacturing area can start the production. If they are unsatisfactory, the design engineers will need to change part of the specifications or reduce parts to obtain the desired end result.

7.3 Conclusion

This section explains briefly how an implementation of the methodology can theoretically work in Windchill, which data at which step is required and how the interface could be done. Having a well-maintained database is quite expensive. However, to prove all of these steps, it must be implemented in future case studies to show advantages.

8 Future work and perspectives

In this section, I propose that the methodology can be improved with a continuation of research into it. This is necessary for obtaining an end result so that companies can really use the whole methodology. One part of this approach is already explained on a conceptual level, that is CBR. Moreover, research is still necessary to make it possible to use on the market.
Improving on manufacturing strategies is a track that guides companies to stay competitive in today's market. In particular, our understanding of MPM has to be continuously improved.
The following paragraphs point out the weaknesses, necessary improvements and perspectives of the framework.

MPM capacity

In MPM, the exact capacity of the factory is given. This approach takes, as given, the needed capacity for each product or project. In other words, this cost estimation approach does not take into consideration the possibility of reaching over-capacity or under capacity, not even for necessary future investigations for layout changes. This methodology requires the needed capacity of machines to be available and if it is the contrary it will not be taken into consideration. Currently it is the responsibility of the MPM engineer to manage the capacity.

Link the methodology with a working ABC system

If the company decides to use the methodology, it should also implement ABC for the entire enterprise so that information can be linked. After starting with production, the estimated costs can be controlled and adapted if any differences occur. This help to find out the real price of manufacturing one product. In general, having the exact knowledge about its price allows for the achievement of better results in the future and more specifically within the methodology.

A link between capacity and outsourcing

The methodology does not take care of the capacity, which is left and not used after the outsourcing decision. It has to be considered, whether or not outsourcing adds considerable advantages. If not, it is better to leave it in house, in order to utilise the machines and the workers. Regardless of whether the work is outsourced or done in house, some overhead costs are always present.

Extraction of CAD models for CBR

As mentioned before, the proposed methodology should be applied for mass production manufacturing, meaning that, by today’s standards, all items exist in a CAD format. In order to find the most similar items, the database needs to save and compare STEP files, which are a special type of CAD format. Some research should be done in this area because the CBR part of the approach was explained in a conceptual way.

Indicators

Indicators should be added to each manufacturing process, to support the MPM engineer in choosing the manufacture processes of a certain product. Finally, it will speed up the time to market because a pre-selection of the best processes is possible and one must not wait until the end for improvements. The indicators will also support the MPM engineers and less experienced employees in their work. .

Database

The database in this master thesis is used like a black box, which means its immediate use is not possible. However, all the requirements are given, so all the necessary information for creating the database is available to make the methodology work.

Context of application in the future

However, more suitable industrial business cases will be the necessary in order to better validate and assess the methodology. This methodology is geared towards large factories that produce several different products. The methodology can be applied in all different kinds of companies.

9 Conclusion

The purpose of this thesis is to describe the importance of the early use of cost estimation in the product development process. A new methodology was developed in this thesis, which allows the user to utilize Life Cycle Costing (LCC) in Manufacturing Process Management (MPM). The thesis examined all the existing cost estimation approaches and takes the two that are the most suitable to define a new methodology.

The developed methodology consists of three main tools: Case Based Reasoning (CBR), Activity Based Costing (ABC), and Outsourcing. The main advantages of this technique would be money saving, the development of more efficient new products, reduced time to market and increase the quality. In fact, this method is more suitable for manufacturing companies, who mass-produce their products; otherwise the work would not be worth it because the methodology is linked to consumption of time and expenses.

Furthermore, an experimental study has been conducted to demonstrate the methodology in the calculation of the manufacturing as well as the product costs. If a company uses this methodology, the benefits could provide several advantages in the completive industry. Through the implementation of this novel methodology, companies will have the potential to increase efficiency to higher profits and decrease their wasteful activities.

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List of Abbreviations

ABC	Activity Based Costing
ACDR	Activity Cost Driver Rate
AI	Artificial Intelligence
BOA	Bill of Activities
BOM	Bill of Materials
BPNN	Back Propagation Neutral-Network
CAD	Computer Added Design
CAx	Computer Aided x
CBR	Case Based Reasoning
CCR	Cost Centre Rate
CNC	Computer Numerical Control
CRM	Customer Relationship Management
DoD	Department of Defence
DSS	Decision Support System
eBOM	engineering Bill of Materials
EOL	End of Life
ERP	Enterprise Resource Planning
FEM	Finite Element Method
IDA	Institute of Defence Analyses
LCC	Life Cycle Costing
mBOM	manufacturing Bill of Materials
MPM	Manufacturing Process Management
MRP	Material Requirement Planning
NC	Numeric Controlled
OP	Operating profile
PCE	Product Cost Estimation
PDM	Product Data Management
PLC	Product Life Cycle
PLM	Product Life Cycle Management
RD	Resource Driver
SCM	Supply Chain Management