Total Cost of Ownership

- Revealing the true cost of owning and operating equipment

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Abstract

Title: Total Cost of Ownership
– Revealing the true cost of owning and operating equipment.

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Core issue: "Which costs should be included in a general Total Cost of Ownership model regarding centrifuges, and what input variables are needed in order to calculate those costs in a user-friendly way and with a maintained level of accuracy?"

Purpose: The theoretical purpose of the thesis is to identify the cost items that have the greatest impact on a TCO calculation for a centrifuge. The practical purpose is to develop a generic model and tool for calculation of TCO where cost elements with high impact on TCO are prioritised. The objective is to reduce the number of input variables and thereby increase the usability of the model.

Methodology: Theory studies of life cycle concepts, case studies of the centrifuge in the brewery and vegetable oil application and interviews with specialists, are some of the different activities that build the base for this thesis. In order to contribute to the field of the research many different perspectives were used and both qualitative and quantitative data have been collected.

Conclusion: In the Total Cost of Ownership study it was found that eight cost elements constituted 90 percent of TCO. These elements all made an impact of more than five percent each. Some cost elements could be excluded since they contributed with less than one percent each. These findings enabled the development of a tool for calculating TCO with a decreased number of cost elements to consider. Thereby a less complex TCO analysis is enabled.

Keywords: Total Cost of Ownership, TCO, Life Cycle Costing, Life Cycle Profit Activity Based Costing, centrifuge

Acknowledgments

Working with this thesis has been one of the most exciting and interesting projects we have ever taken part in. Not only has it given us valuable insight and knowledge about the Total Cost of Ownership concept, it has also introduced us to Alfa Laval and the business environment in Latin America.

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Lund, May 8th 2008

Anna Bladh & Anna Ström

Table of content

1 Introduction

This chapter gives the reader an understanding for the objective and the purpose of this thesis. In order to reach this understanding, it is of interest to explain the authors approach to the issue. The background behind the idea to this thesis will be explained and the proposed core issue the thesis aims to investigate will be defined.

1.1 Background

The customer demand of information about costs that occurs during the entire product life cycle has increased. Therefore interest of the Total Cost of Ownership concept (TCO) that captures and measures cost over the product life cycle has increased. It is important for organisations to understand their customers' cost structure, as well as the relative distribution of different costs during the life cycle in order to optimise the cost of ownership.[1]

In recent years several trends have contributed to an increased interest for TCO. The trends among others are; increased emphasis on the quality of purchased materials and services, rationalisations of supplier bases, increased global competition and growing recognition of the significance of purchasing expenditures.[2]

A TCO calculation is valuable in different situations. In a sales situation it can provide the selling organisation with information to justify a higher initial price with lower cost of ownership. A study can work as an active part in a pricing strategy and provide knowledge that contributes to a more accurate initial price of equipment. [3]

A study can also serve as an important source of information when pricing service agreements. It can constrain the selling organisation from losses due to higher maintenance costs than expected, and the customer from getting disappointed with to high prices on service agreements.[4]

Among the greatest benefits of TCO, is improved decision making. A TCO study can highlight the most costly areas. Hence create opportunities for quality improvements and cost savings, which support the organisation's continuous improvement efforts.[5]

Although TCO is seen as a great concept for calculating lifetime cost it is rarely used in practice. This is due to the complex process of gathering the cost information that needs to be included in a calculation. Therefore, if a TCO model is going to be used, it is vital that the used model is applicable with not to many input variables so that the

[1] Göran Berg, interview 2008-01-14
[2] Ellram, (1993) p 49
[3] Ahlmann, (1998) p 1071
[4] Göran Berg, interview 2008-01-14
[5] Ellram, (1993) p 51

researcher is able to reach a result in the end. Otherwise, if the model is to complex there is a risk that the researcher give up somewhere in the information gathering process.[6]

1.2 Discussion of issue

The main objective for a TCO analysis is to understand and optimise the ownership cost of equipment. In general those analyses are performed within the organisation itself. However, at times it is interesting for an organisation to obtain a better understanding of its customers' different costs when discussing service agreements, and knowing how to price services and parts.[7]

A TCO model has been developed for this cause recently in corporation with Alfa Laval, and a case study of the cost of ownership of centrifuges in the oil sands industry contributed with inputs. The model is currently only applicable for a specific centrifuge in the oil sands application, although TCO analyses are interesting for many customers. Therefore it is of interest to develop a more generic model for centrifuges that can be used on other applications and not only for the oil sands application.[8]

The interface of the developed model is not user-friendly and therefore it is demanding to operate the model. The model requires the user to have total access to a large number of costs and information; otherwise it can not be used.[9] Therefore it is of interest to develop a model with improved user friendliness and to progress the model in a way that the number of needed in-parameters will diminish.

The term user-friendly in this thesis stands for the ease with which people can employ the model. The user friendliness depends on the number of variables needed to calculate the TCO cost and how hard it is to attain those numbers.

It is especially valuable to be able to use the model on applications with a lack of historical cost data. The greatest challenge for an analysis made on a more unknown application is to estimate all data needed. Therefore it is favoured if a new model with a reduced number of invariables can be developed.[10] This model will be called the HIT model because its focus on the **H**igh **I**mpact elements on **T**CO.

The better the accuracy of the invariables used, the greater the reliability of the TCO analysis achieved. Further, costs that make up a greater proportion of the total cost affect the accuracy of the result more than costs of smaller proportions. It is interesting to investigate how different cost elements affect the outcome of the analysis and which elements that influence the result the most.

[6] Ferrin and Plank, (2002) p 19
[7] Michaela Boye, interview 2008-01-08
[8] Ibid.
[9] Göran Berg, interview 2008-01-14
[10] Ibid.

1.3 Core issue

The following issue is proposed for this thesis:

“Which costs should be included in a general Total Cost of Ownership model regarding centrifuges, and what input variables are needed in order to calculate those costs in a user friendly way and with a maintained level of accuracy?”

1.4 Purpose

The theoretical purpose of the thesis is to identify the cost items that have the greatest impact on a TCO calculation for a centrifuge.

The practical purpose is to develop a generic model and tool for calculation of TCO where cost elements with high impact on TCO are prioritised. The objective is to reduce the number of input variables and thereby increase the usability of the model.

1.5 Delimitations

Delimitations of the work include:

- The case study of a known application will be restricted to one customer in the brewery application located in Latin America.
- The case study will be conducted on centrifuges at the position of green beer clarification in the brewery process.
- As an unknown application, the use of centrifuges for extracting vegetable oil will be the application studied.
- The HIT model will only be usable for centrifuges. Theoretical findings are though applicable on other equipment and on other industries as well.

1.6 Target groups

The thesis is mainly intended for people within the academic world, i.e. professors, teachers and other students, and for employees at the Parts & Service department at Alfa Laval, who want to deepen their knowledge about the TCO concept. Other target groups are found in other divisions at Alfa Laval or in other organisations that are interested in the TCO concept.

1.7 Abbreviations

Reappearing abbreviations in this thesis that can be good to know are the following once:

ABC	Activity-based costing
ABM	Activity-based management
LCC	Life Cycle Cost
LCP	Life Cycle Profit
TCO	Total Cost of Ownership

2 Methodology

This chapter intends to present the methodological approach behind this thesis. Aware of the method used, the reader will get a better understanding of how the work proceeded and of the result of this thesis. It will also provide information about the quality of the data collected and of the effort made to increase the validity of the thesis.

2.1 Approach to the issue

What costs to include in the HIT model depends on how much the cost items will affect the result. Some cost elements will in a general picture be that small that they will not affect the result much compared to others. It is beneficial to put the effort on collecting more accurate cost information about the cost elements that make higher impact and exclude the cost elements that contribute less.

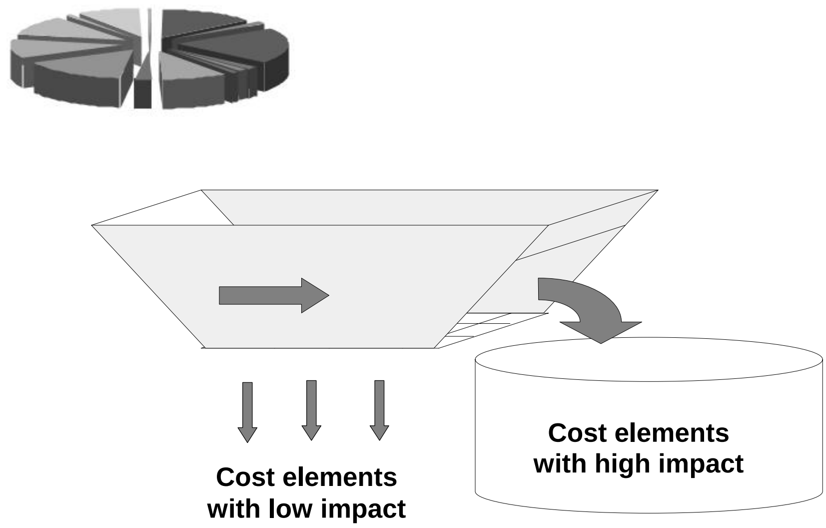

Figure 1 When deciding what cost elements to include, the ones that matters the most will be sorted out from the ones who make less impact on the total cost.

Regarding needed information, the objective is to decrease the number of needed variables, in order to make sure that the HIT model is user-friendly. Figure 2 shows the desired result regarding number of inputs. When reasoning logic about it, the reality seems to be as the straight line shows, i.e. the greater number of input variables added, the more accurate the total cost becomes. The study aims to find a way to use a smaller number of input variables and still keep the result at the same accuracy level.

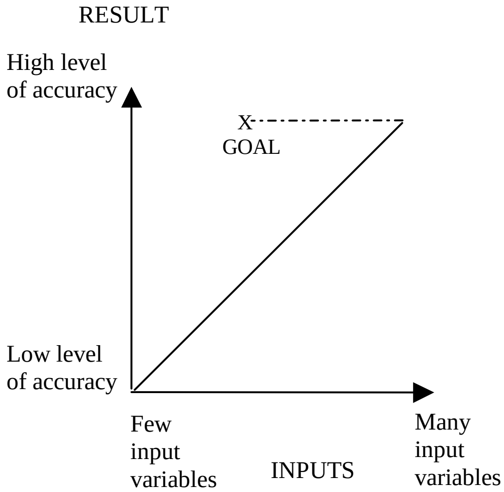

Figure 2 The result's level of accuracy in relation to number of input variables.

2.2 Methodology versus the issue

As the mission of the thesis is well defined, the methodology will have to be established with the issue under consideration. This way of letting the issue set up the methodology exists in the research world today, as well as the opposite way; letting the methodology establish the issue.[11]

It can also be advantageous to use many different perspectives in this thesis. It can be beneficial both regarding the methodological approach, and when considering the theoretical framework. Different perspectives will increase the contribution of diverse thoughts and create more innovative ideas to this field of research.

2.3 The system approach

A lot of differences were found when the use and cost of centrifuges in the oil sands industry were compared to the use and cost of centrifuges in the brewery business. Experiences from Berglund's and Ericsson's study were not easily applicable to this study. This is in line with what the system approach implies. It believes in an objective reality where different parts affect each other so that the whole is not the same as the sum of the parts. The approach counts in synergies, and knowledge is always dependent on the system. [12]

[11] Nilsson, (1994) p 2
[12] Bjerke, (1981) pp 7-8

The study performed by Berglund and Ericsson has been the starting point for this study. Some of their ideas from the TCO analysis for centrifuges in the oil sands application were considered. Experiences achieved from one study can only be used as aids for making analogies in another study, the system approach claims. This is if the studied systems have a similar content.[13] The setting of the centrifuge study in the oil sands application differed a lot from the setting in the brewery application. There were many specific details that mattered in the centrifuge oil sands study. The system approach assumes the reality to be more complex than a more analytical approach and interactions in the system between parts must be considered when conducting a study.[14] The system approach will, for those reasons, be used in this study.

2.4 Qualitative and quantitative data

The system approach advocates qualitative studies rather than quantitative ones. It believes it to be better if the researcher interacts and aims to understand, instead of making a passive study.[15] It can be very synergetic to combine both qualitative and quantitative data. [16] In the case study performed, both qualitative and quantitative data have been used.

When developing the total cost of ownership concept valid for this thesis, different techniques were used such as; interviews, discussions and literature studies in a qualitative way. During the case study at the brewery on the other hand, data was collected in a quantitative manner. All data was unfortunately not available to obtain in a quantitative way and at those occasions the data was based on qualitative assumptions. For those figures, many peoples' opinions of what numbers to count with have been collected. To fully understand the cost structure and the different drivers for the cost it was vital to do some qualitative research. There were opportunities to interview many employees on different positions in an organisation that had done some research themselves on the total cost of ownership.

Quantitative data can reveal relationships that otherwise are hard to find, and it can also prevent the researcher from being carried away by qualitative data that sometimes can give false impressions. Quantitative data can also give direct suggestions to new theory which can be valid with help of quantitative data.[17] There is a need for both types of data, because the hard data gives us a base for theories, while the soft data explains the relationships found and therefore enables the building of theory[18].

[13] Bjerke, (1981) pp 7-8
[14] Ibid. pp 7-8
[15] Ibid. p 11
[16] Eisenhardt, (1989) p 538
[17] Ibid. p 538
[18] Mintzberg, (1979) p 587

2.5 The case study approach

A case study approach is particularly appropriate in areas concerning new topics. The focus of a case study is to understand the dynamics in one single setting. In a research, either one or many cases can be studied and many different data collection methods can be used such as interviews, archives, observations and questionnaires. Case studies are used to provide description or to generate or test theory. A well defined focus, a research question, is good to have before starting the research. Hence, the researcher can work more systematic to gather specific data needed. Though, the focus may shift on the way when new findings give new perspectives to the research.[19]

The customer in the brewery industry was chosen to be the main case study mainly because of practical reasons. The brewery announced in an early state to Alfa Laval that they were interested in the research approach and that they wanted to be involved and could contribute with the data needed. The fact that the customer wanted to share their data, increased the chances of gathering all data needed and that was essential when the case selection was made. A less detailed study made on centrifuges in the vegetable oil industry will also contribute with findings to this thesis.

In order to improve the model and create the HIT model, the case studies can contribute with important information. Critical outcomes from a case study can give knowledge about data less easily obtained, for which extra concern has to be directed on how to estimate when there is lack of historical information. Empirical data from the more unknown application vegetable oil will be used when verifying the HIT model.

2.6 Interviews

Complementary insights and different perspectives contribute to more empirical data gathered, and increase the chance of capturing important insights. More faith can also be put into the findings made.[20] One way to gain different perspectives during the empirical study is to conduct interviews in teams of two persons. One person is interviewing, i.e. interacting with the information source, while the other person take notes and then have a more distant perspective.[21] Some of the interviews in this study have been conducted by two persons. Other interviews have been performed one by one and that has also contributed to two slightly different perspectives to the research. This has resulted in the gathering of slightly different facts, giving rise to different ideas which has stimulated self questioning within the working unit.

[19] Eisenhardt, (1989) pp 532-536
[20] Ibid. p 538
[21] Ibid. p 538

2.7 Criticism of sources

One of the greatest challenges during the case study at the customer in the brewery industry was the language barrier. The customer visited for the case study was located in Latin America and many of the employees had limited knowledge of the English language. Though both the authors of this thesis have some Spanish skills it was not always enough. Many questions had to be repeated and sometimes long explanations were necessary. This resulted in misunderstandings, and some of those were not revealed until some time afterwards. This means that information from some persons could be inaccurate. To prevent incorrect information to be used, an extra carefulness has been applied and many people have been asked the same questions. Numbers have also been compared to standard Alfa Laval figures to see if they seem to be in the same range. When numbers differed significantly from the Alfa Laval's numbers, it has been a reason to query the findings even more.

Part of the data is primary information, taken from the control system of the centrifuge or from the organisation's SAP system. Others are secondary data in shape of assumptions or interviews conducted with interpreters. Because of this the data has been questioned many times during the research and a lot of the information collected has been confirmed by specialist from respective area.

It is impossible to get absolute numbers regarding all the production in the past and to know all the circumstances. The time aspect forced limits to be drawn on how detailed the study could be performed and how exact numbers that could be achieved. It has been important to get as good numbers as needed to get the desired level of accuracy of the TCO analysis. On some of the cost categories, consumptions or costs were attained only for some few months. Logic assumptions then had to be done for the missing numbers, e.g. that one kind of consumption was proportional to another one that was available for the same months. Sometimes the same information was attained from different sources and they differed slightly, and then again the info needed to be questioned and a new search for more correct numbers started.

When conducting interviews, it was considered if the responses perceived were based from personal experience or if it was secondary data given to the person interviewed. A lot of information was perceived from the persons that perform the activities the questions regarded, which increases the validity of the answers.

2.8 Work breakdown structure

The work behind the thesis can be described through the following steps:

1. Study of the total cost of ownership concept and closely related theories – both by studying literature and by interviewing specialists in the field of research.

2. Study of the brewery application – reading about the industry and interviewing brewery experts.

3. Preparations for the total cost of ownership case study – including interviews at Alfa Laval Parts & Service and Brewery Technology, in Tumba Sweden and in Brussels, Belgium.

4. Case study: Performed in the brewery application at a customer in Latin America – the case study approach and interviews are used and both quantitative and qualitative data are collected.

5. Calculations and analyses of the outcome of the case study – a system approach is used and all data are put together.

6. Study of the vegetable oil application – a fictive case study is created, mostly qualitative data is used and it is collected through interviews with specialists.

7. Identify the cost elements with the greatest impact on TCO – is done by comparing the impact of all the cost elements identified from the two studies.

8. Prioritise cost elements into primary and secondary inputs – is done by taking into account how big impact they have on the TCO and how hard they are to attain.

9. Identify needed invariables for these cost elements – see how they can be calculated in a convenient, but still accurate way.

10. Develop the HIT model for centrifuges – using the case studies, all the quantitative and qualitative data collected, taken into account the system approach and using the theoretical framework built up.

11. Verify the HIT model – testing the model with numbers attained from the detailed study. Making sure the developed model with much less invariables, gives an answer that is close to the calculated value containing many more cost elements.

3 Theoretical Framework

This chapter gives the reader an understanding of the life cycle concepts and the cost management concepts. In order to understand the practical objective of the thesis, it is vital to have knowledge about the theoretical framework that serves as a foundation.

The theoretical framework applied in this thesis consists of life cycle concepts and cost management concepts. The life cycle concept Life Cycle Costing (LCC) will be described in order to explain the background and interest of measuring cost over the whole lifespan. Life Cycle Profit (LCP) will enlighten why it is important to not only focus on costs but also consider profits. Total Cost of Ownership (TCO) will be described to explain the foundation and ideas behind the structure of the HIT model and also in order for the study to take on a customer perspective. Regarding cost management, Activity Based Management (ABM) will be described in order to explain why the usage of life cycle concepts is valuable and strategically important. Finally, Activity Based Costing (ABC) will contribute in building a logic structure of the model for calculating TCO.

Life Cycle Cost	Explains why it is of interest to measure costs over the whole lifespan.
Life Cycle Profit	Enlightens the importance of not only focusing on cost, but also on profit.
Total Cost of Ownership	Suggests a suitable perspective to take on when focusing on customers. TCO also serves as the foundation the model and tool are constructed from.
Activity Based Management	Explains why life cycle concepts are strategically important.
Activity Based Costing	Contributes in building logic structure when developing the HIT model and tool.

3.1 Life cycle concepts

3.1.1 Life Cycle Cost analysis

Customers of today put less focus on initial investment price; instead they are interested in a long-term perspective where all costs that will occur during the lifetime of an asset are considered.[22] Such analyses are called Life Cycle Cost analyses (LCC). There are several approaches for making LCC analysis. According to Woodward (1997);

[22] Ahlmann, (1998) p 1069

"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 and to the end of its useful life."[23]

LCC involves estimations and calculations of costs on the whole life basis and includes the development cost that occurs before the investment decision is made[24]. The LCC approach shifts the focus from initial investment to a long-term perspective on the investment decision process[25].

Fabrycky and Blanchard's (1991) definition of LCC is similar to the one of Woodward (1997) and includes: research and development costs, production and construction costs, operation and maintenance costs and retirement and disposal costs[26].

LCC analyses are useful when comparing different options before investment decisions. LCC analyses are also applicable when calculating the cost of ownership of assets, analysing different maintenance methods, minimising the total LCC cost and convincing customers of the quality of one's equipment.[27]

White and Ostwald (1976) categorised the costs of LCC into engineering and development costs, production and implementation costs and operating costs[28].

Definitions of LCC of Woodward, Fabrycky and Blanchard and White and Ostwald have a common view of what costs LCC analyses include. These are conception and development costs, manufacturing costs, operation and maintenance costs and costs of disposal of the equipment. The engineering and development costs become interesting since the design and development of an asset causes a major part of the future maintenance costs[29].

When defining the cost elements to include in a LCC analysis, the elements have to be carefully evaluated so that elements that are estimated to have little impact can be excluded. When comparing different investment alternatives, sunk costs and costs that are similar among different alternatives can be excluded. [30] There are elements that are considered to have a heavy impact on an LCC cost analysis, and hence critical to capture. These are; the time period between failures, the time period between overhauls, the time period of repairs and scheduled maintenance and the energy usage rate. [31] The traditional opinion about how equipment breakdowns are spread over lifetime is that the probability of breakdowns is higher in the start-up

[23] Woodward, (1997) p 336
[24] Ibid. pp 335-344
[25] Durairaj et al., (2002) p 35
[26] Fabrycky and Blanchard, (1991)
[27] Ahlmann, (1998) p 1071
[28] White and Ostwald, (1976)
[29] Ahlmann, (1998) p 1069
[30] Wååk, (1992) p 1
[31] Stevens, (1976) pp 55-56

phase of equipment and after a longer time of operation.[32] These assumptions give the breakdown curve in Figure 3.

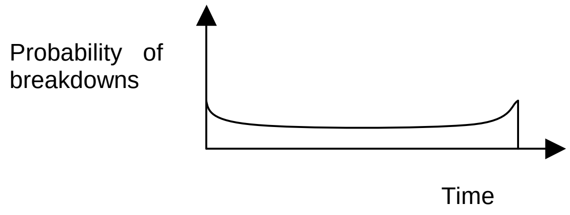

Figure 3 Equipment breakdowns over lifetime[33]

However recent research shows that the majority of breakdowns have no connection with time of operation. Only three percent had a curve similar to the one in Figure 3 while almost 40 percent showed a curve similar to the one in Figure 4. The remaining percentage showed several different curves that either had higher cost in the beginning of the operating life or higher cost in the end of the operating life. There were also curves that were continuously increasing and curves that had slightly lower cost at the beginning of the lifetime. The curve in figure 4 was the most common curve.[34]

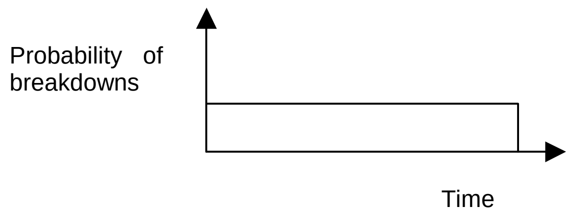

Figure 4 Equipment breakdowns over lifetime[35]

It is of great importance that the life cycle time period is appropriate and carefully evaluated,[36] since the forecast life of an asset has great impact on the LCC analysis. There are five possible determinants of an assets life expectancy, functional, physical, technological, economic and legal lifetime.[37] According to Henriksson it is the economical lifetime of an asset, not the depreciation plan, which is applicable to use when calculating LCC. Henriksson also states that taxes can be excluded from the calculation.[38]

[32] Hägg, (2007) pp 1-2
[33] Ibid. pp 1-2
[34] Ibid. pp 1-2
[35] Ibid. pp 1-2
[36] Wååk, (1992) p 2
[37] Woodward, (1997) p 338
[38] Tomas Henriksson, interview 2008-02-06

3.1.2 Life Cycle Profit analysis

In the business environment of today, where high focus is put on increased revenues and profits, it is not sufficient to only emphasise on costs. Manufacturing equipments are primary installed to generate revenue and hence increase profit. Therefore the concept of LCC has been extended with the concept of Life Cycle Profit (LCP). LCP is the difference between LCC and the life cycle revenue and therefore closely related to the LCC concept.[39]

LCP is concerned with the estimation of overall life cycle surplus, and manufacturing companies have shown that availability of equipment have a larger effect on revenue than on costs. Hence, involvements of maintenance in both early and late stages of the life cycle are not only good for decreasing costs but also for increasing revenues.[40]

3.1.3 Life Cycle Cost and Life Cycle Profit analyses

LCC and LCP are not different methods but rather adaptations to the business environment. LCC is applicable in a stable environment, while LCP is applicable in a more dynamic and turbulent environment. LCC is often used when the organisation is cost-oriented and the focus is on internal efficiency, i.e. doing the things right. When focus is on revenue and external efficiency, i.e. doing the right things, and flexibility is highly valued, LCP is more applicable.[41]

The business environment of today is characterised by a dynamic market with a rapid technical development. The rate of uncertainty is increasing and flexibility becomes more important. However, in reality the choice of method might lay in between the concept of LCC and the concept of LCP. For instance, it can be useful to consider both the approaches when analysing economical consequences during an asset's lifetime.

[39] Idhammar, (1996) p 41
[40] Ahlmann, (1998) pp 1072-1073
[41] Ibid. pp 1073-1074

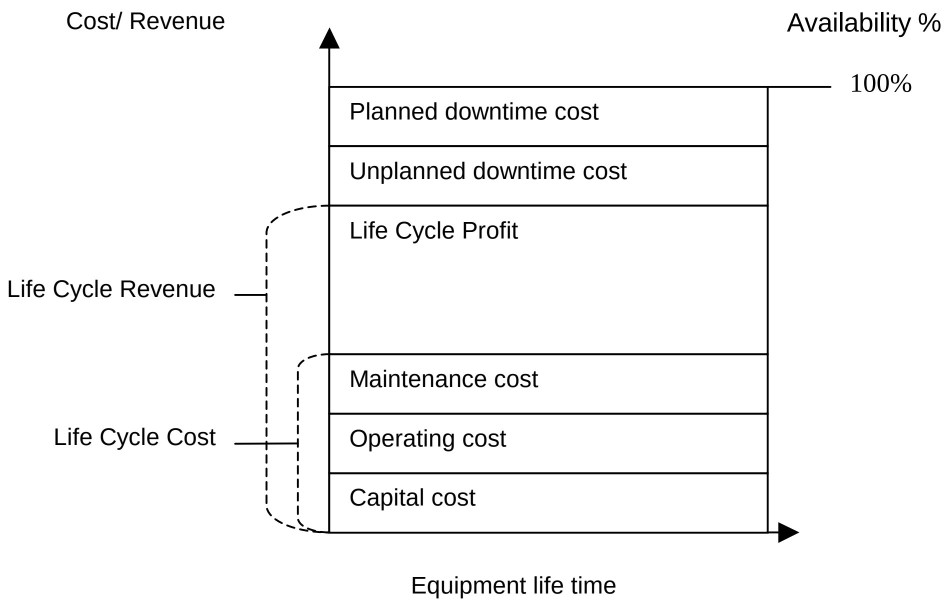

Figure 5 The connection between Life Cycle Profit and Life Cycle Cost.[42]

3.1.4 Total Cost of Ownership

Total Cost of Ownership (TCO) is both a purchasing tool and a philosophy, which strives to understand all the costs that will occur during the lifetime of an asset up to the disposal of the asset. TCO concerns about Life Cycle analysis but holds a slightly different approach than LCC.

Costs that should be taken into consideration when calculating TCO are pre-transactional, transactional or post-transactional. Pre-transactional costs occur before the acquisition, e.g. supplier selection. Transactional costs are costs related to the purchase of an asset, while post-transactional costs are costs that can be associated with the usage of the asset during its' lifetime and the costs associated to the disposal of the asset. It is important to notice that TCO analyses concern purchase price but not the development costs that the manufacturing company might have had. [43]

A significant part of a TCO analysis is to identify the most critical cost items that will have the greatest impact on the total cost of ownership[44]. The TCO analysis will not provide exact figures; instead it will be useful as a comparison tool in investment decisions and decisions about whether it is time to replace equipment or not[45].

[42] Idhammar, (1996) p 41
[43] Ellram, (1993) pp 49-50
[44] Ibid. pp 49-50
[45] White, (2006) p 28

The most common barrier to the usage of a TCO model is the lack of data recourses. Other common barriers are the lack of training, the lack of education and the corporate culture of an organisation. The corporate culture becomes a problem when contradictions exist about the appliance of TCO.[46] The information needed to complete the model exists, but since it is so many variables to consider, the job of collecting and consolidating the information is complex. Adoptions of TCO among organisations are limited because of this complexity.[47] Surveys show that purchasing directors and managers are often familiar with the TCO model. It is though hardly used because of its complexity and the lack of integration between the data systems that contain all the information needed.[48]

A problem arises from the fact that how the machine is operated, affects how often the machine has to get maintenance and service. Doing a TCO analysis can provide better preventive maintenance practices and prevent emergency repairs which often becomes costly. [49] It is also suggested that a TCO model should consider how many hours the equipment is used. This should be done by comparing the results for when it is heavy, moderate or light used, with help of so called heavy, moderate and light use numbers and compare those hours of usage.[50]

Other costs that have a high impact on TCO are the costs associated with downtime, i.e. when a machine is not working because of breakdowns, maintenance or service. During downtime, there will be a cost for an alternative process or loss of income.[51] Three different approaches can be used when developing a TCO model. The first is a monetary based method, which is allocating costs of an investment to different cost components or activities. This method is precise but time consuming and often complex. The second approach is the value-based method which combines monetary data with quantitative information, e.g. information about supplier rating scores. The third approach is to use a mathematical programmed decision model.[52]

Ellram and Siferd (1993) propose a framework for the development and implementation of the TCO concept. According to Ellram and Siferd, stage one is to identify the need and interest of TCO which must be driven by internal interest or external pressure. Stage two is to determine the items of interest.

The third stage is to form a TCO team that represent different expertises of the organisation. Stage four includes the identification of relevant costs, which could be done through a brainstorming session or a cause and effect diagram. In the search for costs which should be included in the TCO model, it could be helpful to study specific activities. When defining the cost of acquisition, activities which can be related to the investment of the equipment should be studied. The activities that are

[46] Ellram, (1993) pp 49-50
[47] White, (2006) p 30
[48] Ellram and Siferd, (1993) p 2
[49] White, (2006) p 30
[50] Ibid. p 29
[51] Fonseca, (2001) pp 1-2
[52] Hurkens et al., (2006) p 28

performed during the lifetime of an asset can be studied in order to specify the cost of ownership.[53]

In the process of identifying activities and cost-drivers an activity-based-costing approach could be useful.[54] When relevant costs have been identified the most critical costs have to be determined. In most cases; 20 percent of the cost elements counts for 80 percent of the total cost. Thus, it is necessary to identify the elements that have the greatest impact on the total cost and the costs that are important for decision making. Critical costs often include cost of maintenance and cost of downtime.[55]

In the process of determining critical cost elements it is, as a the first step, suggested looking at the identified activities and determining; which activities consume the most time, the cost of those activities, what drives the level of these costs and which cost information is available. The next step is to determine how to get hold of the needed information and in the case when information is not easily obtained; if it is worth the effort to collect the information. During this process, data systems and accounting records can act as useful resources. Step number three in the process is an information gathering step. It is in this step of great importance to keep records of the data resources and note if there is information not available or usable, and if there is information based on assumptions. The fourth thing to do is to test and implement the model; this includes entering the costs into the model. The fifth step is to analyse the result of the model in order to see if it seems reasonable, and if all the critical elements are included. In some cases it could be of interest to make a sensitivity analysis to confirm the impact of the different elements. [56]

When stage five is completed the data is ready to be used in decision making. In many cases the process stops here and begins again in stage one the next time a TCO analysis should be done. Stage six describes how one can take advantage of a TCO model through integrating it into a control system. It can for example be the organisation's supplier monitoring system, education and training system or the ERP system. The last stage includes updating and maintaining the TCO system to secure that the system is supporting the organisation's efforts.[57]

When there is service included in the TCO analysis, it is proposed to perform a process analysis of the service to realise what activities are related to the service. These activities can be both physical and administrative. When activities are identified, a cost driver analysis is to be carried out with the objective to see which cost should be included in the analysis.[58]

[53] Ellram and Siferd, (1993) pp 2-3
[54] Porter, (1993) pp 38-42
[55] Ellram and Siferd, (1993) p 3
[56] Ellram, (1993) p 51
[57] Ibid. p 51
[58] Hurkens et al., (2006) pp 30-32

3.1.5 Total Cost of Ownership and Life Cycle Cost

Total Cost of Ownership and the concept of Life Cycle Cost are both built on the idea that costs must be analysed from a long-term perspective and that other costs than the initial investment cost should be included in the analyses. Moreover the concepts support the idea that a supply manager must analyse the impact of different business functions, when valuating a specific investment. The concepts also enlighten the importance of measuring all activities associated with a purchase to value an investment situation correctly.[59]

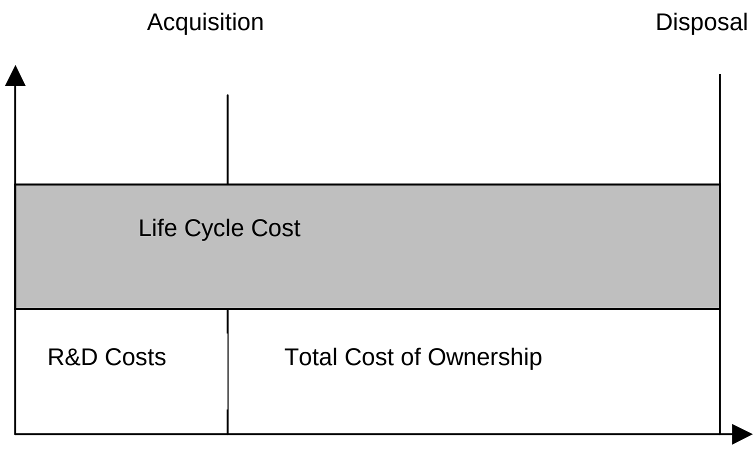

Figure 6 TCO concept compared to the LCC concept

3.2 Activity Based Management

Activity Based Management (ABM) focuses on the most profitable usage of organisational resources. ABM refers to the actions that can be taken on a better information basis with Activity Based Cost information.[60]

The advantage of ABM is that the concept emphasises the impact made by each service or product on the organisations costs. The link which is provided by ABM; between products or services, and resources, can help managers to make better forecasts by predicting recourses which are required for a certain volume.[61]

The advantages of ABM can be resumed in key benefits which are: reliable information about accurate costs of products and services, knowledge about the

[59] Ferrin and Plank, (2002) pp 18-27
[60] Kaplan and Cooper, (1998) pp 137-138
[61] Plowman, (2007) p 23

impact of individual activities on profitability. ABM also enables organisations to make more predictable forecasts.[62]

3.2.1 Activity Based Costing

The concept behind Activity Based Costing (ABC) is the thought that all activities performed by an organisation, are performed in order to support production or distribution of the organisations products. Therefore all costs should be regarded as cost of products.[63] ABC focuses on activities and the resources consumed by activities in order to analyse organisational spending.[64] According to Kaplan and Cooper (1998), an ABC model can be seen as an economic map of the organisation's expenses and profitability based on organisational activities.[65]

An ABC system consists of at least three components; resources, activities and products. Resources can be defined as factors of production, which are needed in order to perform activities. Activities, on the other hand, are processes performed by humans or machines. The logic behind ABC is that resources are consumed by a reason. Activities are performed to sell performances and different products or customers create demand of activities. Therefore it is logical that the cost of an activity is allocated in relation to different products claim on the activity.[66]

The greatest difference between an ABC calculation and a traditional calculation is that a traditional calculation often fails to allocate overhead costs. Traditional calculations allocate overhead costs using arbitrary bases like direct labour hours.[67]

An ABC budget is allocating overhead cost through the consumption of activities. The allocating of indirect costs and overhead costs is the key issue ABC aims to solve. Resource drivers are factors used when costs are to be allocated to activities. Activities are consuming a certain amount of resources and can be seen as resource transformation processes. Activity drivers are used to allocate costs from activities to products.[68]

The construction of an ABC calculation can be structured in four stages. The first stage is to "develop an activity dictionary"[69]. This includes the identification of activities performed by indirect and support resources. Examples of activities can be; to perform maintenance on machines or clean machines, activities can be described by verbs. Activities that use less than five percentage of an individual's time or resource capacity are often ignored.[70]

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[62] Plowman, (2007) p 25
[63] Gerdin, (1995) pp 62-71
[64] Kaplan and Cooper, (1998) p 107
[65] Ibid. p 79
[66] Gerdin, (1995) pp 62-71
[67] Kaplan and Cooper, (1998) p 83
[68] Gerdin, (1995) pp 62-72
[69] Kaplan and Cooper, (1998) p 85
[70] Ibid.

Stage two is to "determine how much the organisation is spending on each of its activities"[71]. Resource cost drivers link expenses to performed activities. Quantities of resource cost driver of resources that are none personnel are often based on direct measurements or estimations. When linking resource spending to activities performed the objective is to be approximately right instead of precisely wrong.[72]

Stage three is to "identify the organisation's products, services, and customers"[73] and involves analysing whether the activities are worth doing. The last stage is to "select activity cost drivers that link activity costs to the organisation's products, services and customers"[74]. The fourth stage is concerned with the linkage between activities and cost objects, cost objects can be products, services and/or customers. Activity cost drivers are quantitative measures of outputs from activities.[75]

The choice of activity drivers

In the choice of activity drivers there are two fundamental questions needed to be asked: how many activity drivers are needed, and what kind of activity drivers should be chosen? [76]

A common rule is that the more accurate the calculation, the more activity drivers are needed. If the products are consuming equal amounts of the activities, these activities can be regarded as one. Hence the number of activities has decreased. When deciding how many activities are needed, it is important to consider the impact of one activity on the total cost, if the activity is causing a great amount of the total cost it is of extra importance that the activity drivers are correctly chosen.[77] The cost of operating a detailed ABC calculation greatly exceeds the benefit gained such as improved decision making.[78]

In the decision regarding which activity drivers to choose it is important to consider the availability of information and the possibility of measuring data. The ambition is that the cost of measuring data can not be greater than the cost of a wrongly chosen activity driver.[79] Activity drivers can be divided into three categories: transaction drivers consider the number of transactions i.e. how often an activity is performed. Duration drivers are concerned with the time an activity requires to be performed. Intensity drivers charge for the amount of resources used each time an activity is

[71] Kaplan and Cooper, (1998) p 85
[72] Ibid. pp 85-89
[73] Ibid. p 94
[74] Ibid. p 95
[75] Ibid. pp 94-95
[76] Gerdin, (1995) pp 62-72
[77] Ibid. pp 62-72
[78] Kaplan and Cooper, (1998) pp 102-103
[79] Gerdin, (1995) pp 72-89

performed. Intensity driver should be used only when the activity is expensive to perform or when the time varies each time the activity is performed.[80]

3.2.2 Total Cost of Ownership and Activity Based Costing

According to Porter (1993), an activity-based structure should be used when identifying and collecting critical costs for a TCO analysis[81]. The concept of TCO is logical and easy to understand and an activity-based model will make costs easier to understand and collect[82]. If an activity-based structure is applied it is crucial to identify the cost drivers related to activities, this is often perceived as a challenging task. Findings from surveys, shows that organisations are unsure of their ability to identify critical cost drivers, and cost drivers differ among organisations. Despite that, groupings of commonly used cost drivers have been presented. The categories that are suggested and examples of cost drivers of each category are cost drivers for:[83]

Operation:	manufacturing, machine efficiency, assembly cost and labour savings
Quality:	unplanned downtime, customer downtime and inspection
Logistics:	freight, packaging, availability and lead-time
Initial price:	unit cost and initial capital expenditure
Opportunity cost:	cost of money and overhead
Maintenance:	training, downtime, labour, spare parts and preventive maintenance
Inventory cost:	safety stock, storage and turnover
Transactions cost:	administration and post-purchase agreements and procurement
Life cycle:	life of product, long-term usage and cost savings over life of product

It is proposed that a set of core cost drivers should be used, which are suitable to the organisation and if the TCO model needs to be more specific, additional drivers can be added. This supports the building of a modular TCO model.[84]

3.3 Theoretical discussion

Life Cycle Cost concepts are of interest in the investigation of what costs that can be referred to as the cost of the acquisition and usage of an asset. The concept of Total Cost of Ownership takes on a slightly different perspective than Life Cycle Cost theories in the sense that TCO focuses more on costs that will affect the buyer and user of an asset. Therefore TCO is a suitable life cycle concept when analysing cost from a customer perspective. There is no commonly used definition of TCO.

[80] Kaplan and Cooper, (1998) pp 95-97
[81] Porter, (1993) pp 38-42
[82] Ellram, (1993) p 49
[83] Ferrin and Plank, (2002) pp 24-26
[84] Ibid. p 26

However, research about the concept all agree on that cost connected to the purchase, operation and disposal of equipment should be included in a TCO calculation. In this thesis TCO will include the costs categories:

- Cost of Acquisition (COA)
- Cost of Ongoing Production (COP)
- Cost of Maintenance (COM)
- Cost of Downtime (COD)
- Cost of Disposal (CVOD)

The definition of TCO that will be used in this thesis is:

TCO = COA + COP + COM + COD + CVOD

The abbrev of cost of disposals is CVOD since it is possible that cost of disposals is a value, in many cases equipments are sold back to the manufacturer or on the second-hand market. Therefore "cost" of disposal is called CVOD.

An investment in an asset is made in order to increase returns; therefore it is not sufficient for a cost analysis to only consider expenses as costs. To be more customer focused, cost analyses also need to consider lost profits as costs. If the asset is going to be integrated in a manufacturing system, it is of interest to see the impact equipment downtime will have on the production and in the end the impact on profits.

When developing the HIT model and tool for calculating TCO it is of interest to make the model logic in order to increase the user friendliness. Therefore Activity Based Costing will be influencing the construction of the HIT model. The ABC concept will mainly be influencing cost categories where the structure benefits from being grouped into activities.

When developing an ABC model the first stage is to identify activities performed by indirect and support resources. When constructing the TCO model the first stage will be to identify which activities that can be related to the centrifuge.

The second stage in developing an ABC model is to determine how much the organisation spends on the different activities. In the construction of a TCO model the spending on each activity will be investigated through a case study. The case study will also provide information about resource cost drivers through the mapping of resource expenses linked to activities.

The third stage when developing an ABC model is to analyse whether activities or processes are worth doing. This stage will not be taken into consideration when constructing the HIT model since it is more applicable in situations when measuring the contribution of different products to the organisation.

The fourth stage in the process of developing an ABC model is to select activity cost drivers. This stage will be considered when making a quantitative measurement of activities. The concepts of ABC and TCO both agree on that the objective is to make an approximately right calculation. Calculation should not need time consuming pre-studies, instead models for calculating ABC and TCO should prioritise cost elements with great impact on the total cost. When considering which cost elements to include in a model, ABC suggests that cost elements with less impact than five percent should be excluded or none prioritised. Therefore it is interesting to investigate how great the aggregated share of the cost elements are, that individually count for less than five percentage of the total cost. This will be done in order to see if it is realistic to exclude them or make them none prioritised.

4 The original TCO model used as a foundation

This chapter gives a brief presentation of the TCO model that was developed in 2007, in order for the reader to understand the structure behind the HIT model.

4.1 Background on the conducted study

During the spring 2007, a master thesis entitled "New perspectives of the Total Cost of Ownership concept" was conducted by Berglund and Ericsson, at the Process Technology Division of Alfa Laval. This was done by order of Life Science & Separators and Parts & Service, with the purpose of further developing the total cost of ownership concept for a separator within the oil sands application. During the thesis a model, called the ABI model, for estimation of TCO was developed.[85] The main objective of the study was "…to exemplify how a TCO analysis can be used to identify critical cost items and fields of improvement"[86]. Due to lack of financial data the ABI model was partly activity based, and the model was successfully tested at Alfa Laval. Alfa Laval Parts & Service wants the model to be further developed as well as adapted to other divisions and customer segments.[87]

4.2 The structure of the model

The primary structure of the ABI model constructed 2007 by Berglund and Ericsson can be seen in Figure 7.

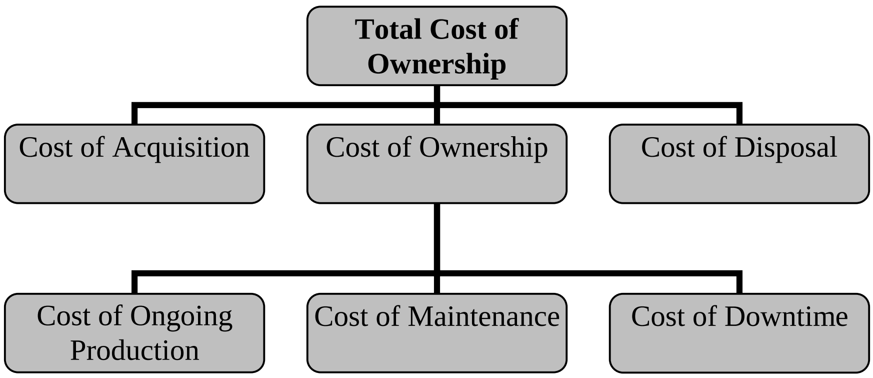

Figure 7 The Total Cost of Ownership structure used as a basic structure.

[85] Berglund and Ericsson, (2007) pp 8-11
[86] Ibid. p 10
[87] Göran Berg, interview 2008-01-14

Berglund and Ericsson wrote that a TCO analysis only should include costs that have a "significant effect on the cost of ownership, if they can be distinguished and calculated"[88]. It is a good notion and they tried to follow it but nevertheless their ABI model could be improved concerning those remarks. In Figure 8, the structure of the excel model developed by Berglund and Ericsson can be seen and it is described in more detail bellow.

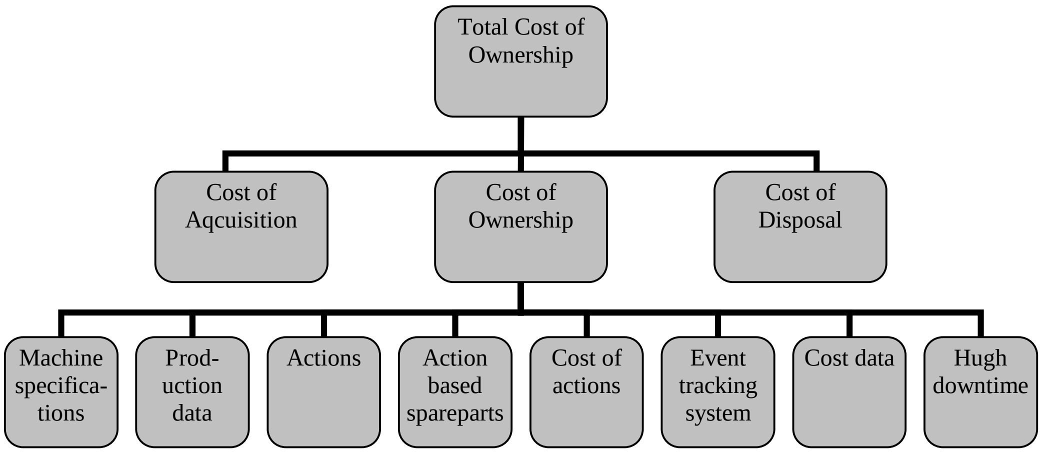

Figure 8 Cost structure of a general Total Cost of Ownership model created by Berglund and Ericsson (1997).

The superior cost categories in the model have been broken down into more specific cost elements. The operator of the excel model have to enter information into twelve Excel sheets. The first sheet is named TCO and works as a summary of sheet number two that calculates cost of acquisition and sheet number three that calculates cost of ownership. The remaining ten excel sheets are used as input sheets where information data is entered. The process of entering data into the model is complicated since there are up to 50 input data per year to enter in some of the sheets.

Because of the limited amount of cost related data in the case study performed by Berglund and Ericsson, part of the information is built on assumptions. Therefore it was practical to use an activity-based structure regarding cost of maintenance. By using an activity-based approach, the cause and effect relationships between the activities and the costs, also turned into being more visible. It made it easier for the user of the model to estimate the costs that can not be feasible and therefore need to be estimated.[89]

Berglund and Ericsson suggest an activity-based TCO model when "the maintenance cost of the equipment is a significant part of the total cost" and "when large costs are

[88] Berglund and Ericsson, (2007) p 46
[89] Ibid. pp 46-80

caused by indirect and support resources" [90]. The first, because a great part of the TCO than can be calculated by an estimation of the most important maintenance activities, and the latter because the costs are easier to allocate with help of tracking activities. In their final TCO model they use an activity based approach only for estimation of spare parts.[91]

4.3 Potential for improvements

When Alfa Laval tried to apply the ABI model developed by Berglund and Ericsson it was found that the model requires too much input information, normally gathered from the customer. The ABI model is not a general model at time being, but rather a specific model for centrifuges in the oil sands industry.[92] Part of the structure is usable, but there is a potential in further developing the structure to facilitate the usage of the model.

There are improvements that can be done in the ABI model to make it more user-friendly and an analysis less time consuming. A reduction in time could though result in a less reliable analysis. Therefore it is important to find out which costs that have the highest impact on TCO in order to decrease the input variables as much as possible. The ABI model was built to suit TCO analyses of operating equipment. There is a great potential to develop the model in order to make it suitable to use when calculating on new applications and customers.

4.4 The oil sands case study

In the oil sands industry the centrifuge is used to separate oil from sands, the remaining product is a light crude oil. This process is tearing and puts high demands on the centrifuge. The case study was, due to complexity of obtaining information, partly based on estimations and assumptions the reliability of the result is therefore unknown.[93] Due to the great differences between the industries, and the unknown reliability of the result from the oil sand case study the oil sands industry case study will not have great impact on the development of the HIT model. The case study will instead contribute with information about the relative impact of cost groups on total cost of ownership and where the greatest differences between industries lie.

The study shows that downtime is a critical cost, and an increase of availability would decrease the cost of ownership. The reason why downtime has such a big impact on cost of ownership is that all downtime in Berglund's and Ericsson's study contribute to income loss which is rather unrealistic. It was also made clear that the cost of ownership far exceeds the cost of acquisition.[94]

[90] Ibid. p 52
[91] Berglund and Ericsson, (2007) pp 46-80
[92] Göran Berg, interview 2008-01-14
[93] Berglund and Ericsson, (2007) pp 80-97
[94] Ibid. pp 80-97

A significant difference from the brewery industry is that the oil sands industry is much more tearing on the centrifuge; hence the maintenance activities are different among these industries. The oil sands case study was performed at a customer who did not buy all spare parts and service from Alfa Laval. Cost of spare parts constitutes to a higher part of maintenance cost in the oil sands industry. This is probably due to that service is not performed by Alfa Laval service engineers.

5 Alfa Laval and separation technology

The chapter will present some facts about Alfa Laval, their service agreements and some separation theory.

5.1 Facts about the company

Alfa Laval is a global provider of specialised products and engineered solutions[95]. To secure long-term performance of equipments, and maintain and develop customer relations, Alfa Laval has a well established service organisation, Parts and Service[96]. Parts & Service supports customers with a secure supply of high quality spare parts, maintenance, training of employees, and technical support[97].

5.2 Performance agreements

To focus on the improvement of their customers processes Alfa Laval has established performance agreements. Performance agreements include a service plan, service kits which contains the priority spare parts needed, stock advice, technical advice, training and performance documentation and verification.[98] Performance agreements are tailor made from the customer's requirements and structured into four levels, giving the customers a chance to choose the most suitable for their specific situation.[99]

Table 1 Alfa Laval's performance agreements

*	Basic professional service
**	Planned service program
***	Integrated expert service
****	Premium partnership

To price performance agreements correctly it is crucial to know the cost of components included in the agreements. Information about spare parts prices and service engineers is often available, the challenge is to know how often parts are being replaced, how often corrective maintenance is needed and how much time the service engineers will need to perform service. Therefore it is of interest to do a Total Cost of Ownership study; such a study will also show the relative share of different cost elements of the total cost. In order to justify a higher capital investment it is of interest to show the cost of maintenance during the asset's lifetime.

[95] www.alfalaval.com, 2008-04-05
[96] Alfa Laval Annual Report 2007, p 6
[97] Ibid. p 8
[98] www.alfalaval.com, 2008-04-02
[99] Ibid.

5.3 Centrifugal separation theory

Alfa Laval manufactures and sells centrifuges. The centrifuges are used to:[100]

- separate solid particles from a liquid, those centrifuges are called clarifiers[101]
- separate two insoluble liquids with different density and in the same time remove solid particles, those centrifuges are called purifiers[102]
- separate two liquids from each other

The separation theory is based on the force of gravity. If a stationary bowl is used, a liquid mixture will clear after a while when heavier particles slowly sink to the bottom of the bowl influenced by gravity. The heavier particles will after some time settle and become a sediment layer on the bottom.[103] In a centrifuge the same theory is applied, but the bowl is rotating very fast and the force of gravity is replaced by centrifugal force. This force is thousands of times greater which results in a much faster separation and sedimentation and it also happens continuously.[104]

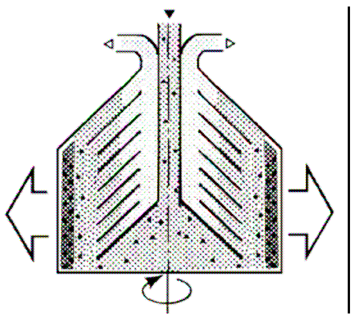

Figure 9 The figure shows a centrifugal separation. From the top; the un separated liquid entering from the inlet and the two separated liquids going out. On the middle the horizontal arrows represent the discharge. [105]

A great difference in density between the two liquids facilitates the separation[106]. During ongoing separation, the sediment that evolves in the bowl is ejected by discharges[107], se Figure 9. Discharges occur continuously during production but the time interval between the discharges differs a lot in different applications[108]. The discharge volume may be small or large and the volume is determined by how long time the bowl is being opened[109].

[100] Operator's Manual, Brew2000 Alfa Laval, p 17
[101] Morgan Persson, interview 2008-04-08
[102] Ibid.
[103] Operator's Manual, Brew2000 Alfa Laval, p 17
[104] Ibid. p 18
[105] Ibid. p 18
[106] Ibid. p 19
[107] Ibid. p 52
[108] Leif Tarberg, interview 2008-04-07
[109] Operator's Manual, Brew2000 Alfa Laval, p 30

6 The brewery case study

The chapter will present the case study performed, how the costs were found and calculated and the findings made.

Beer is a natural product made from malt barley, hops, water and yeast. The brewery process can look different depending on kind of beer produced, equipment used and local regulations.[110] The centrifuges studied in the brewery case, were used in the green beer process, right before the filtering station, to ease the load of the filter. The solid part taken away in this part of the process is yeast.

A case study was performed at a brewery in Latin America with the purpose of investigating the total cost of ownership of a centrifuge.

6.1 The investigated brewery

It has been crucial for the Latin American brewery, to invest in production systems and equipments in order to keep up the market position. The factory is equipped with the latest technology in order to make production as efficient as possible and the quality of the beer as good as possible.[111] The installation of Alfa Laval centrifuges in 2004 was made to increase production capacity as well as increasing the quality of the beer.[112] Today there is no excess capacity and production is running 24 hours a day, almost every day of the year. Therefore an alternative production process is used if the centrifuges are not operating. A great motive for the TCO analysis is requirements of increased production capacity and therefore investment in an additional centrifuge. A study also reveals if there are costs that might be unrealistically high, higher than expected, or errors that occur very often.[113]

During normal circumstances the centrifuges are supposed to run continuously without anyone pushing a start or stop button. Therefore the centrifuges are hardly touched by operators.[114] When the centrifuges are given service, a service engineer from Alfa Laval arrives and two employees working within maintenance are helping out[115].

Installations of two centrifuges were made in 2004; however the centrifuges started to run correctly in 2005. Year 2005 was covered by a guarantee arrangement where Alfa Laval paid up the majority of the costs.[116] Therefore the calculation of total cost of ownership will only include the years of 2006 and 2007.

[110] Separation Sales Manual for Process Industries, Alfa Laval
[111] Manager operations, interview 2008-03-05
[112] Project engineer, interview 2008-03-13
[113] Manager operations, interview 2008-03-05
[114] Operations engineer, interview 2008-03-05
[115] Maintenance engineer, interview 2008-03-12
[116] Project engineer, interview 2008-03-13

6.2 Cost of Acquisition

The cost of acquisition includes all the costs which can be referred to the initial investment of the centrifuge. Those are: cost of the centrifuge, cost of additional equipment, commissioning costs, installation costs and logistical costs.

The initial investment cost of the centrifuge was easily found in the agreement between the brewery and Alfa Laval. The agreement also contained information about the extra equipment purchased at the time of the installation. In this case, the delivery costs were included in the price of the centrifuge. Installation costs counted for a great share of the acquisition cost. Installations were made by external partners and the agreements with external partners made the information available.[117] Training sessions were performed by an Alfa Laval service engineer and therefore included in the agreement price. All of these costs were then summarised and added to the total cost of ownership as cost of acquisition.

6.3 Cost of Ongoing Production

Cost of ongoing production is in this TCO study divided into energy cost, cost of consumable supplies and cost of beer losses. The labour cost for operating the centrifuges could, in this case, be disregarded because the production is fully automated, and no one work regularly with the centrifuges on an every day basis[118].

For calculations of the cost of ongoing production, some information was taken from the control system for the centrifuges at the customer. Momentaneous data points were taken out at a regular time interval, mainly 400 points per months, for the last twelve months. The data points at those particular times gave us an average of, for example, current but it also showed the accumulated value of e.g. running hours and number of discharges.

6.3.1 Energy costs

Average energy consumption was calculated from 400 data points per months on the momentaneous current and production hours. To this calculations the extra energy used for discharges were added by calculating an average value of energy consumption per discharge, multiplied with number of discharges per months. To confine the energy consumption per discharge, 400 data points was collected on the time interval three minutes so at least one discharge was caught per sample. Around ten samples, i.e. three minutes long intervals, were studied and the average from those samples were assumed to be an accurate average of extra energy consumed per discharge. As can be seen in Figure 10, the energy consumption due to discharges does not have a great impact on the total energy consumption.

[117] Project engineer, interview 2008-03-13
[118] Manager operations, interview 2008-03-05

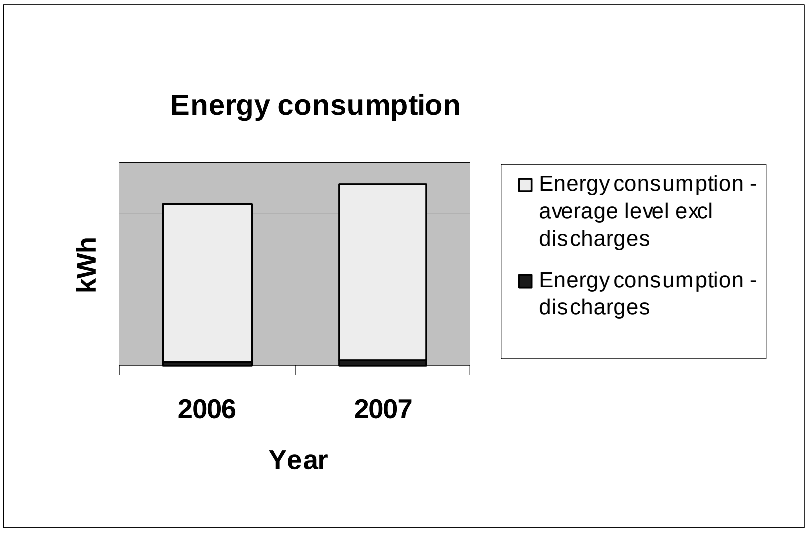

Figure 10 Average energy cost compared to energy consumption due to discharges.

Since the numbers are taken directly from the control system, both the energy for running the production and the energy used when cleaning the centrifuges are included.

6.3.2 Consumable supplies

Water, carbon dioxide and a detergent named oxalat, are consumable supplies used by the centrifuges. The company does not measure water and carbon dioxide consumptions since they were assumed to make a quite small impact on the cost. The water price is low and carbon dioxide is a rest product of the production. The cost of oxalat might have an impact on TCO but it is impossible to determine how much of the chemical that is used only for the centrifuges.[119] It was decided that water costs should be included in this study, because it was thought to maybe have a significant impact on TCO. The costs for carbon dioxide and oxalat was though, left out.

The calculation of water consumption is based on information from the centrifuge installation manual. In order to adapt this information to the case study assumptions for the brewery were made in cooperation with Alfa Laval[120].

It is interesting to see how big proportion of the water consumption that is driven by the number of discharges and how big proportion that is driven by running hours of the centrifuge. Because both the proportions are quite equal they will contribute the same to the water cost and none of them can be excluded if water costs is going to load the TCO analysis.

[119] Manager operations, interview 2008-03-05
[120] Mikael Sjöberg, interview 2008-04-08

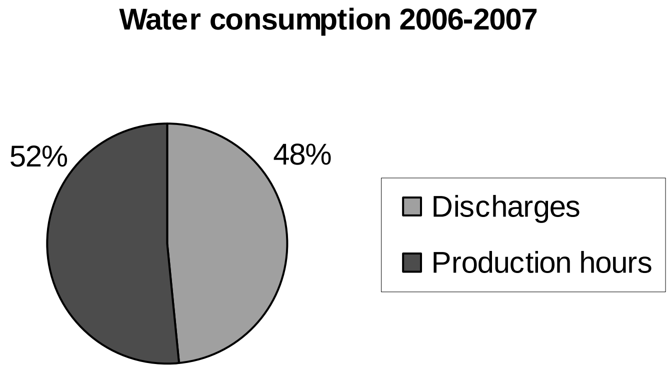

Figure 11 Water consumption due to discharges compared to due to production hours.

The costs for the use of deaerated water, i.e. treated water where air has been removed, have not been able to be attained for this study. Therefore it is left out in the analysis.

6.3.3 Beer losses

When calculating the beer loss from centrifugal discharges, there were problems to evaluate the actual proportion of beer in the discharge volume. At the brewery the centrifuges discharge in average every 2,8 minutes (information taken from the control system) and the discharge volume is around 20 litres (measured in the brewery, confirmed by Alfa Laval). Of this 15 percent of the discharge volume is assumed to be the beer loss, i.e. 3 litres per discharge[121].

The same number of discharges was not used in this calculation as was previously used in the energy calculation. This calculation only includes discharges during production. The numbers of discharges in the production were divided after what kind of brands that were produced. To obtain a cost, the lost beer per brand was multiplied with the production cost for every brand.

6.3.4 Conclusions of cost of ongoing production

A comparison of the cost of ongoing production (energy cost, cost of consumable supplies, i.e. cost for water, and cost of beer losses) and their different impact is illustrated bellow:

[121]Operations engineer, interview 2008-03-05

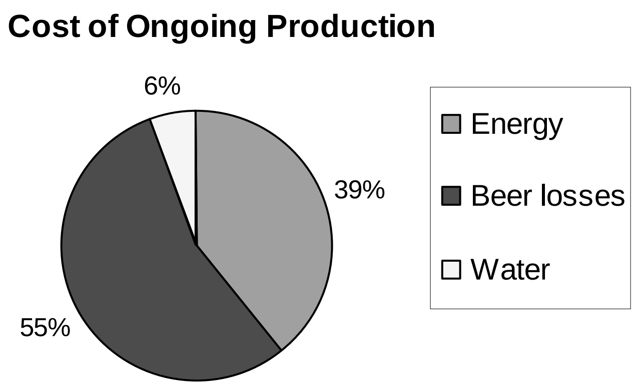

Figure 12 Cost of ongoing production divided into different cost items.

Figure 12 shows that beer losses have the highest impact on the cost of ongoing production and the water consumption only contribute to 6 percent of this cost.

6.4 Cost of Maintenance

The cost of maintenance includes all costs related to maintenance of the centrifuge. These are mainly the costs of spare parts and the costs of service. Preventive maintenance is scheduled and performed every 2000 hour of operations while corrective maintenance is performed whenever there is a breakdown or an error of the centrifuge. Spare parts are grouped into kits, each 2000 hour when preventive maintenance is performed a suitable kit is also used.[122]

The brewery buys all spare parts and service from Alfa Laval[123]. Information about spare parts was found in the invoices send by Alfa Laval to the brewery and in the SAP system at the brewery. In SAP it was also possible to obtain information about the service performed by Alfa Laval. The cost of brewery maintenance employees should also be added to the cost of maintenance. The time brewery employees spent helping out at service occasions were not documented or registered in SAP and therefore this information was challenging to get hold of. Information about how many hours of work that were done were received through interviews with brewery maintenance employees and the Alfa Laval service engineer responsible for the brewery.

[122] Maintenance engineer, interview 2008-03-12
[123] Head of maintenance, interview 2008-03-10

Information received from SAP shows that service is performed and spare parts are replaced according to the schedule. The time required to perform different preventive maintenance activities is known and therefore it is possible to calculate how much time the maintenance employees on site will spend on preventive maintenance of the centrifuge.

Due to the nature of corrective maintenance it is impossible to schedule, the maintenance has to be performed when the centrifuge is out of order. It is also more difficult to predict how long time the maintenance requires. What is known is how long time different maintenance activities will require. At the brewery, corrective maintenance costs are higher than the preventive maintenance cost, this is due to that the brewery have had problems with leakage on the machines, the spare part called liner has caused such big leakage that the centrifuge have had to be turned off and given service.[124] Since it is time consuming to turn off the centrifuge and change spare parts a whole kit of spare parts have been changed in the same time. When the liner has been changed the centrifuge has been given intermediate or major maintenance, such maintenance activities are normally regarded as preventive maintenance activities.[125]

Since the centrifuge had required this maintenance earlier than the scheduled preventive maintenance there are several intermediate and major maintenance occasions documented as corrective maintenance, and hence the cost of corrective maintenance is high.

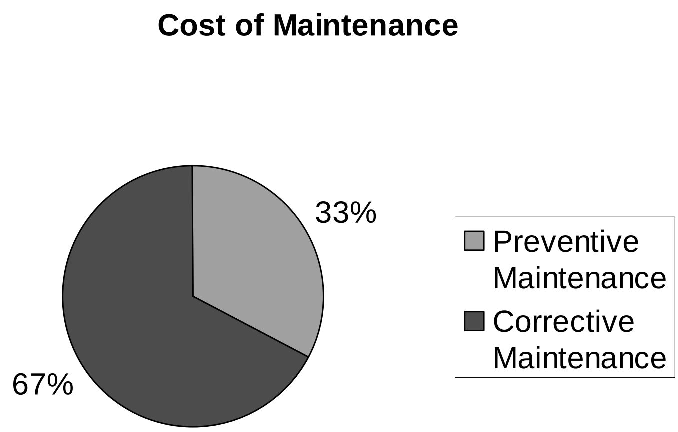

Figure 13 Preventive and corrective maintenance

[124] Maintenance engineer, interview 2008-03-13
[125] Ibid.

The greatest costs of maintenance are the cost of spare parts and the cost of service. The brewery is charged the standard price used by Alfa Laval, included in that price are logistical costs for freight and delivery[126]. The results from the case study of the brewery shows that the cost of spare parts counts for more than half of the total maintenance cost, and the cost for maintenance employees at the brewery is low in relation to the cost of service performed by Alfa Laval and the cost of spare parts.

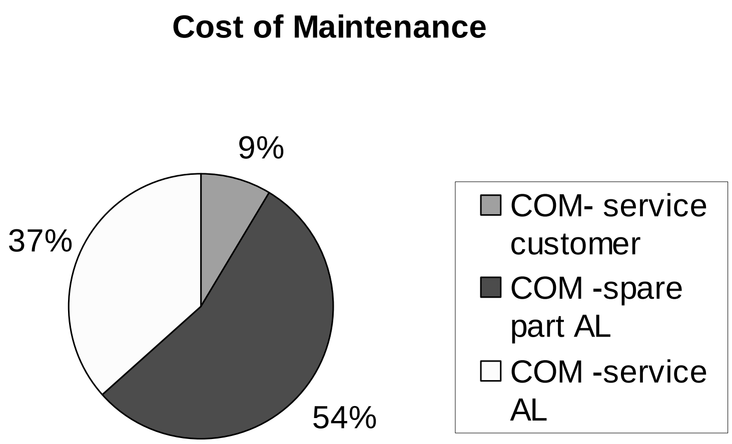

Figure 14 Cost of maintenance

6.5 Cost of Downtime

When the centrifuges are down an alternative process is used. Beer is bypassed the centrifuges direct to the filtration step. Depending on if only one or both of the centrifuges are down, either all beer, or parts of it, is bypassed. The filter is made of a porous powder medium that attract the solid parts of the beer with help of microscopic openings. When those openings are filled with solid parts the filter medium needs to be exchanged. One round, from when new filter is entered into the tank until the filter medium is cleaned out from the tank, is called a filter run. The cost of downtime consists of the cost for the increased amount of the filter medium used in the filter step and the cost of decrease in capacity of the production.[127]

The decrease in capacity emerges because the filters get clogged faster and therefore need to be changed faster, during this extra time the filters can not be used. There are also other costs appertained to an increased amount of filter medium used, according to Alfa Laval there are increased cost of handling, cost of disposal, man-hour costs for preparing a filter run, cost of beer losses due to recharging the filter, and cleaning

[126] Rafael Ordaz, interview 2008-03-03
[127] Operation engineer filtration, interview 2008-03-13

and water costs[128]. At the brewery, there has also been an increase of the use of a chemical called biofine during the time that the beer has been bypassed. This chemical was prohibited in the fall of 2007 and is therefore not longer used.[129] It will never the less constitute a part of our cost analysis regarding the centrifuges for the last two years.

6.5.1 Cost of extra filter consumption

The brewery does not know how much extra filter they use when one, or both, of the centrifuges are down, and therefore this was estimated. The first assumption made was that the centrifuges are most of the time down at the same time, mostly because a lot of the maintenance is performed on both of the centrifuges at the same time[130]. Therefore only two states of conditions have been taken under concern; filtering after all the beer has been centrifuged or after all the beer has been bypassed the two centrifuges. The increased filter consumption during centrifuge downtime was estimated to be 40 percent[131]. This is comparative to the estimation of 44 percent that was used before the centrifuges were bought in payback calculations at the customer[132]. Another estimation on how much more filter that needed to be used when the centrifuges are down is, done by the filtration operating crew, as high as 250 percent[133]. This gives an idea about how much different people's opinions differed in this matter.

The customer was able to give us numbers of the consumption of filter per hl, and the price of filter per hl and year, in general during production, without taking into account if the centrifuges were running or not. With those numbers together with the number of hl bypassed and the assumption of 40 percent increased filter used when bypassed, a cost of the increased amount of filter used was calculated.

The disposal cost of the filter medium is also a part of the extra filter consumption cost and a disposal cost was available as an average per months. (A disposal cost per kg filter was not available.) From this number the cost per hectolitre was calculated, taking into account that the bypassed volume consumes 40 percent more filter. There after this cost has been multiplied with the number of hectolitre beer bypassed. This number is then added to the previously described extra filter cost.

6.5.2 Cost of extra filter recharges

When the amount of filter runs increases, it does not only increase the consumption of filter, it also increases the amount of times the filter medium needs to be recharged.

[128] Mikael Sjöberg, interview 2008-04-09
[129] Manager operations, interview 2008-03-05
[130] Ibid.
[131] Karl Kiovsky, interview 2008-04-09
[132] Project engineer, interview 2008-03-13
[133] Operation engineer filtration, interview 2008-03-13

This cost includes cost for the increased amount of man-hours to prepare a filter run and the beer lost at every recharge of the filter.

A capacity decrease with 40 percent also means that the filters will be changed 40 percent more times. The brewery had information about how often a new filter run started and what the flow to filtration in general was per hour[134]. With those numbers it was calculate how many more filter runs that needed to be done on the bypassed volume, compared to how many runs that would have been necessary for the same volume, if the centrifuges had been working. The amount of beer lost at every recharge was approximated in hectolitre per recharge[135]. This amount was multiplied with the increased amount of filter runs. A cost for extra number of working hours per recharge was also added as causing a small impacting on TCO.

6.5.3 Cost of biofine

The chemical biofine was earlier used to ease the separation of yeast from the beer. As described earlier, it is now forbidden to use the chemical and that is because of environmental reasons. Never the less the chemical was used earlier and the amount increased when the centrifuges were down. The monthly consumption of the biofine has been obtained, and an assumption from the brewery that the consumption of biofine is around 2 g/hl when the beer is bypassed.[136] Information attained was also that the brewery was not going to use any biofine during the production when the centrifuges were running[137]. Therefore the increase is expected to be 2 g/hl. The increased amount of biofine has been multiplied with a yearly average price for the chemical.

6.5.4 Cost of decreased capacity

The use of centrifuges result in a decrease of the solid load on the filter in the next step of the process and that is the main reason why the centrifuges are used, i.e. without centrifuges the filter need to be changed more often[138]. During downtime of a centrifuge, the run length of the filters decreases, resulting in a decrease in capacity. One way to put a price on the decrease in capacity is to calculate on the value of the lost production during that time, i.e. a value of the decrease of the production in comparison to the possible value of the production with centrifuges.

The approximation of the decrease in capacity in the case study is once again 40 percent after discussions with Alfa Laval[139]. Hence, the lost production volume where calculated as 40 percent of the volume bypassed. The profit of the lost production is calculated in profit per hectolitre from the customers’ annual report.

[134] Manager operations, interview 2008-03-05
[135] Mikael Sjöberg, interview 2008-04-18
[136] Manager operations, interview 2008-03-05
[137] Project engineer, interview 2008-03-13
[138] Mikael Sjöberg, interview 2008-04-09
[139] Karl Kiovsky, interview 2008-04-09

The cost for decreased capacity becomes large compared to the other costs related to downtime, Figure 15 illustrates the proportion.

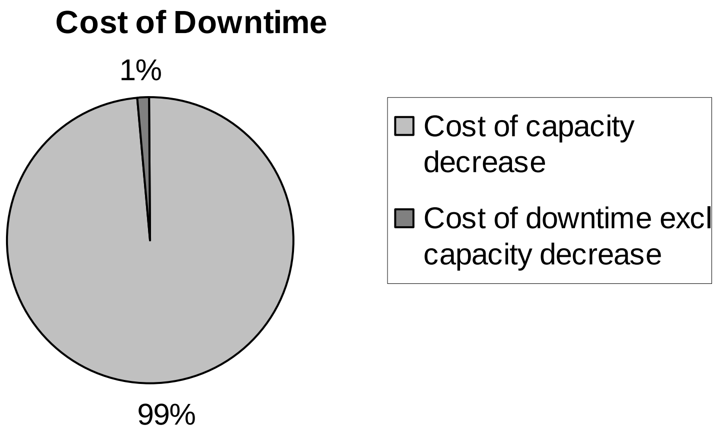

Figure 15 Proportions – cost of capacity decrease compared to the other costs related to downtime.

The cost capacity decrease has an enormous impact on the cost of downtime and it is hard to know how to relate to it. Of course it can be argued that the rest of the equipment could probably not keep up with production at full capacity and therefore the production lost up to full capacity should not be calculated in this way in the study. On the other hand one can argue that because the brewery is trying to use the whole capacity and they even want to increase their capacity it should be calculated this way. As can be read in section 3.1.2, availability of equipment often has a larger effect on revenue than on costs. The actual lost income of not being able to use the equipment is a cost that often is disregarded to a high extent.

6.5.5 Negligible costs

An increase in the amount of filter usage increases handling cost. This was though a cost that the customer could not provide[140]. This cost is assumed to be fairly small in comparison to the increased costs for the filter[141], and it is therefore neglected in the study.

An increased work load on the filtering process also gives rise to increased downtime due to higher wear and tear[142]. It is though reasoned that this increased downtime is quite small and that it can be included in the capacity loss and the increased amount of man-hours.

[140] Manager operations, interview 2008-03-05
[141] Mikael Sjöberg, interview 2008-04-09
[142] Ibid.

There will also be an increased cost of water and cleaning per recharge[143]. But the fact is that the increased number of filter recharges, when the centrifuges are down, is in this study small. If the water costs and the costs for cleaning are fairly small, this whole contribution can be omitted. In this case study it is assumed that those costs are small and negligible. This is according to the customer and they do not even measure water consumption[144]. Of those reasons it is left out from the case study.

6.5.6 Conclusions of cost of downtime

As was shown in section 6.5.4, the cost of the capacity decrease is enormous compared to the other cost (and that is the case even when it is compared to all the cost in the TCO analysis, see section 6.7). Therefore that cost is excluded below, when it is shown how the other downtime costs are in proportion to one another.

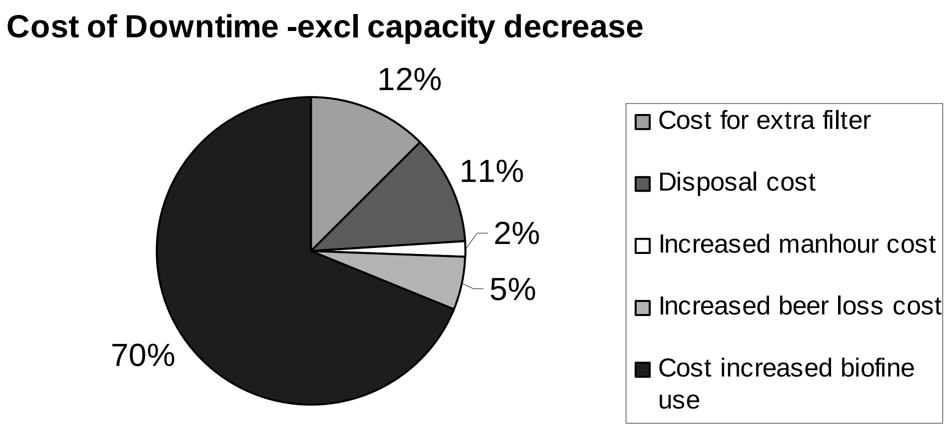

Figure 16 The different proportions of cost items in the downtime cost when the cost for capacity decrease is neglected.

As can be seen in Figure 16, the cost of the extra biofine used has previously had the highest impact on the total cost when the centrifuges stops working, it is 70 percent of the total cost of downtime (when the cost for capacity decrease is excluded). However, as stated before, the brewery is not using this chemical anymore. Therefore, it is interesting to also look on the proportion when both the cost for capacity decrease and the cost of biofine are excluded.

[143] Ibid.
[144] Manager operations, interview 2008-03-05

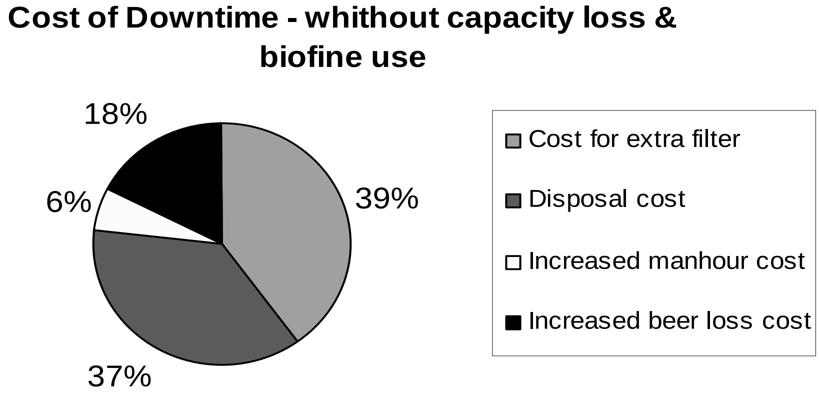

Figure 17 Cost of downtime when both capacity decrease and the cost for biofine are neglected.

Increased man hour cost is a really small part of the cost of downtime, in the figure above it only counts for 6 percent of the total. A cost driver for this cost is the increased number of filter recharges and that number is small in this particular study.

6.6 Cost of Disposal

The cost of disposal includes all costs or revenues which can be referred to the disposal of the centrifuge. When the lifetime is ended the centrifuge will either be discarded or sold back to Alfa Laval or a centrifuge dealer. The brewery counts with a residual value of three percent of initial price.[145] Therefore a value of disposal of three percent will be used in the calculation.

According to Alfa Laval the cost for disposals of a centrifuge will under normal circumstances be the labour cost of disassembly and sending the centrifuge to the junkyard which takes about two days. If the centrifuge is in a good shape it could be sold back to Alfa Laval, then there will still be the cost of disassembly, and a cost for packaging, but there will also be an income of about five percent of the initial price.[146]

6.7 Conclusions of the brewery case study

If the cost of capacity decrease during downtime is included, calculated in the way it has been calculated in this study, see section 6.5.4, this cost will determine the whole TCO value for the centrifuges in the study. The proportion is calculated to be 91 percent of the total cost for the two years 2006-2007, see Figure 18.

[145] Accountant, interview 2008-03-07
[146] Lennart Bergström, interview 2008-04-14

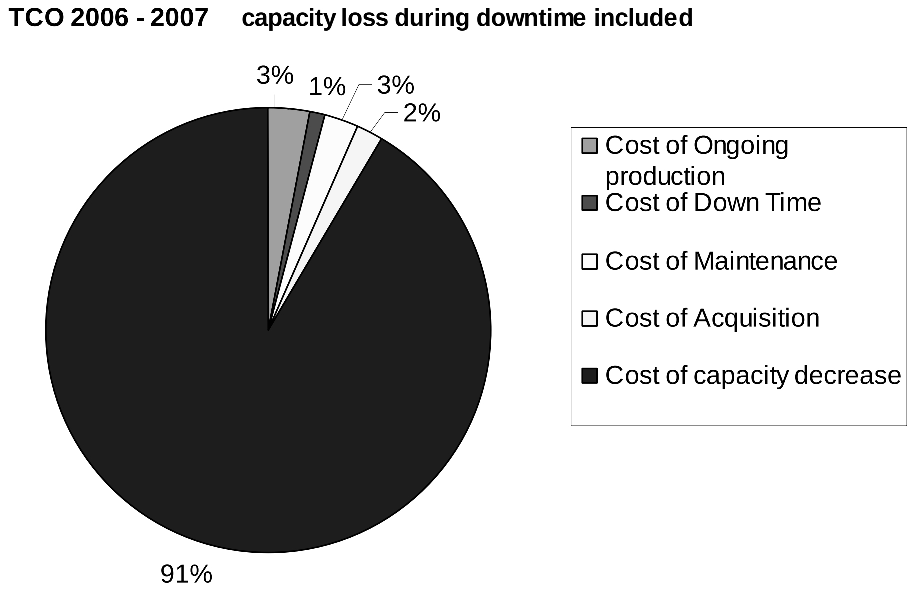

Figure 18 TCO for year 2006-2007 when the capacity loss during downtime is included.

As has been discussed, the cost for the capacity loss is a huge cost that should be taken into account in some way. But for now it will be left aside, in favour for the other conclusions that can be drawn from this case study.

Figure 19 presents a summary of the costs in this study, with capacity loss during downtime excluded. 13 different cost elements are included in this study where of seven elements stand for 90 percent of the cost. This diagram shows that some costs affect the result much more than the other ones. Nevertheless, a great effort has been put on finding all those costs. The amount of effort put down has not at all been proportional to the contribution of each cost to the analysis.

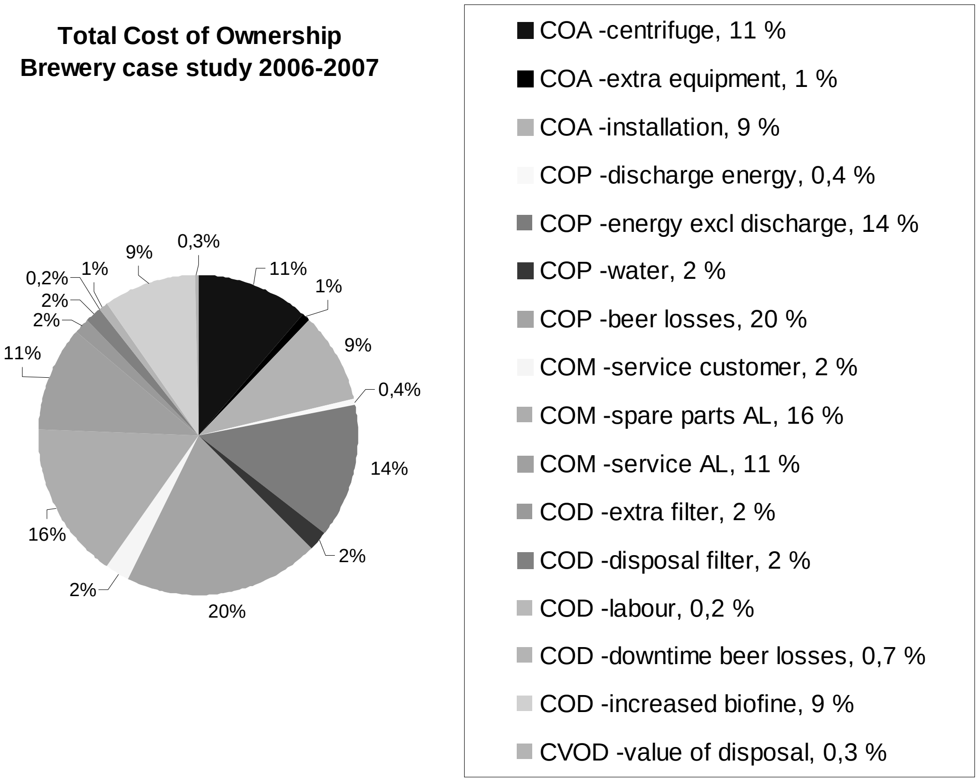

Figure 19 The contribution of every cost element on the Total Cost of Ownership of the centrifuges in the brewery case study (with the cost of capacity decrease during downtime excluded).

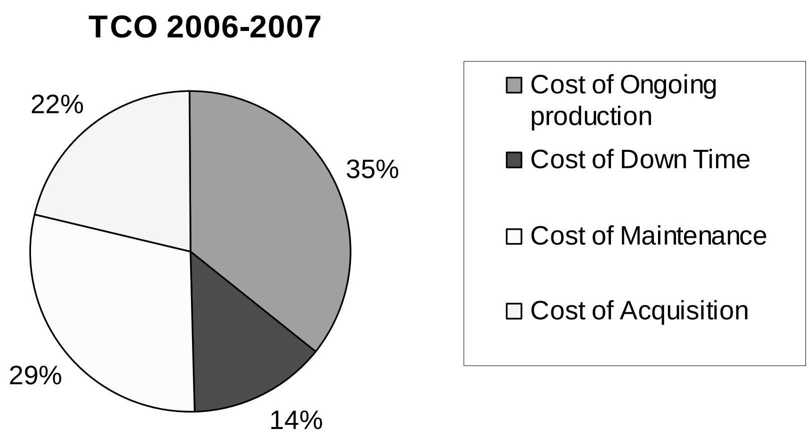

Figure 20 TCO summed up in cost areas, with capacity decrease excluded.

7 A study of the vegetable oil application

A more brief study has been made on centrifuges in the vegetable oil application. A discussion of how the use of centrifuges differs in the vegetable oil application compared to in the brewery application is interesting in order to develop a general TCO tool for centrifuges.

The reason why this application was chosen to be studied is because it is a relatively new application for centrifuges to operate in. Because it is a new and more unknown application, Alfa Laval needs to know the TCO to be able to negotiate during new sales, and when setting prices on spare parts and service agreements. From a theoretical view, it is interesting to look at a second application as a complement to the case study already described, when developing the HIT model. The model is going to be used in settings described above, i.e. the developed tool can give a hint of the TCO value even when information is not that easily obtained.

Alfa Laval centrifuges started to come out on the market for the vegetable oil application in year 2005 and many systems have been under start-up during year 2008[147]. Vegetable oil can be made of e.g. rapeseed oil, palm oil, animal grease and disposed material[148].

7.1 A comparison of the use of centrifuges in the vegetable oil versus the brewery application

Centrifuges in the vegetable oil production are used in different stages of the vegetable oil production process[149]. In this study we focus on the use of centrifuges in a stage called the transesterification stage.

There are some differences between the uses of centrifuges in the vegetable oil application compared to the brewery application. First, every centrifuge is more critical in the vegetable oil application. The plants do normally not have centrifuges in parallel, and therefore problems with a centrifuge can cause downtime for the whole production.[150]

Centrifuges can either be purifiers or clarifiers, as seen in section 5.3. A clarifier free a liquid from solid particles; e.g. it takes away yeast from the beer in the brewery application, while a purifier separate two liquids from each other while removing any solids present at the same time. Glycerine is removed in the vegetable oil

[147] Morgan Persson, interview 2008-02-22
[148] Morgan Persson, interview 2008-04-08
[149] Ibid.
[150] Morgan Persson, interview 2008-02-22

transesterification step. In the vegetable oil application centrifuges are used either as a purifier or as a clarifier.[151] In the brewery case study only clarifiers were studied.

7.2 Cost of Acquisition

The cost of acquisition for the vegetable oil application differs depending on what kind of centrifuge the customer need, what size it is and if the machine needs to be explosion-proofed (depending on where in the process it is used). If an explosion-proofed system, i.e. a system that use an inert gas, is needed the cost of acquisition per centrifuge will increase. Otherwise the cost for installation, the commissioning cost and other costs that have to do with the acquisition are comparable to the costs for acquiring a brewery centrifuge system.[152]

7.3 Cost of Ongoing Production

In the vegetable oil application, as well as in the brewery application, not many man hours are needed to operate the centrifuge. The labour cost for operating the separating system in those applications have a very low impact on TCO and is therefore negligible in this application study.[153]

Energy cost depends on the size of the centrifuge and how much of the capacity the customer chose to use. Hence, it depends on the size of the engine and on the nominal power consumption of the centrifuge. Other parts that consume energy are the pump that feeds the centrifuge and also the control system. There is no difference in what power is used for in the both applications. But the amount of power used differ some, this is also the case when different customer are compared to one another.[154]

Water is in general used in the same way in the vegetable oil centrifuges as it is used in brewery centrifuges. The consumption of water is though about 25 percent less in the vegetable oil application because the centrifuge discharges not that often compared to centrifuges in the brewery application.[155]

The gas used in the centrifuge during vegetable oil production is normally nitrogen gas. A gas is always used in the transesterification stage of the vegetable oil process and in 30 percent of the washing centrifuges. In the case a gas is used, approximately one cubic meter gas per hour is used during production but more gas is needed during start up. [156] In the brewery application the cost of carbon dioxide was assumed to be negligible, because the amount used was small and because carbon dioxide was a by-product in the brewery plant.

[151] Morgan Persson, interview 2008-04-08
[152] Morgan Persson, interview 2008-04-08
[153] Morgan Persson, interview 2008-02-22
[154] Ibid.
[155] Morgan Persson, interview 2008-05-07
[156] Ibid.

Product losses in the vegetable oil application are in the transesterification step and consist of losses of the by-product glycerine. The centrifuge only discharges once an hour, as mentioned earlier, the volume of glycerine lost is little (approx 1-2 litre/hour). Therefore this cost is not at all in the same range as the cost of beer loss in the brewery application.[157]

7.4 Cost of Maintenance

If the use of a centrifuge in the green beer clarification is compared to the use of a centrifuge in the transesterification step, the centrifuge in the brewery discharge much more often. In our brewery study the machines were discharging approximately every third minute and in the transesterification in a vegetable oil process the centrifuges discharge around once every hour. Therefore the vegetable oil application is less tearing than the brewery application. In general the vegetable oil is also a quite harmless application because it works with oil that serves as a lubricant. The needed maintenance is approximated to be almost the same in the two applications. There are exceptions from this regarding two maintenance activities that are not needed to be performed in the vegetable oil application.[158]

7.5 Cost of Downtime

Cost of downtime is probably the cost that differ the most in these two applications. As mentioned earlier, the production of vegetable oil is more likely to stop when the centrifuge is malfunctioning than it is in the beer production. This is mainly because centrifuges are not often running in parallel in the vegetable oil plant, and there is not either many other equipment to use for the separation. Cost of downtime in the vegetable oil application can therefore be counted as a loss of income.[159] When counting on loss of income during downtime of production, the cost can increase very fast. This was shown in the brewery case study, when the capacity loss was transformed into a loss of income. The downtime is though approximated to be quite low in the vegetable oil application, normally there should be next to no downtime[160].

7.6 Cost of Disposal

The cost of disposal is calculated in the same way in both of the applications. The impact of this cost or value depends on what the customer decides to do with the equipment when the lifespan has run out. Hence there is no difference in value or cost regarding the applications.

157 Morgan Persson, interview 2008-04-08
158 Ibid.
159 Ibid.
160 Ibid.

7.7 A fictive case study of the vegetable oil application

In order to have another application to use when developing and testing the TCO tool, a fictive case study for the vegetable oil application was put together. The numbers entered into the TCO tool are numbers for one of Alfa Laval's larger centrifuges for this application. The setting for the centrifuge is thought to be a standard setting in the transesterification stage, and the production hours entered is 8200 hours. Cost elements different contribution can be seen in Figure 21 bellow, while Figure 22 shows the same costs but divided up in cost categories.

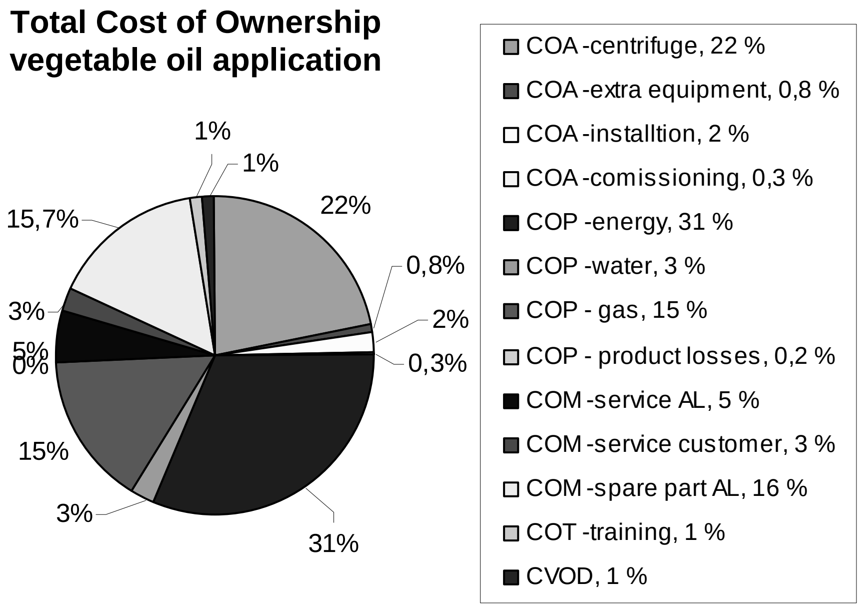

Figure 21 The contribution of every cost element on the Total Cost of Ownership of the centrifuges in the fictive vegetable oil study.

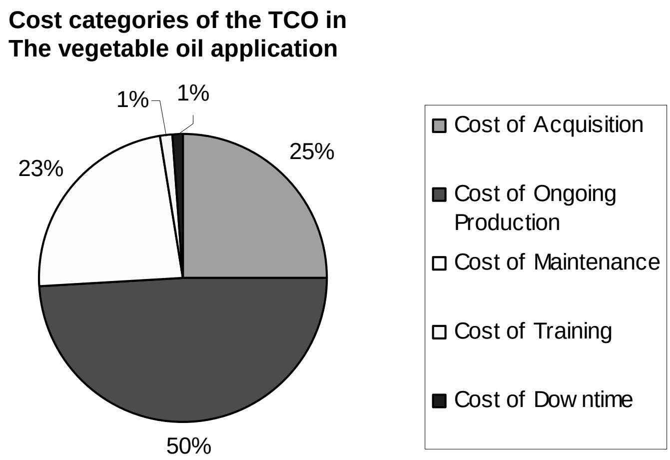

Figure 22 TCO summed up in cost categories.

8 Analysis

This chapter presents the analysis of the findings from the brewery case study and the study of the vegetable oil application. Relationships between cost elements are discussed and a suggested structure of the HIT model is presented, taking into account the impact of different cost elements.

8.1 Potential improvement of the existing TCO model

The potential for developing the existing TCO model can be summarised in four points:

- Find the costs with highest impact on TCO in order to exclude cost elements with low impact from the model.
- Facilitate the usage of the model by decreasing the number of input variables.
- Develop the model so that it can be used when cost and operating information are missing or not measured.
- Develop the structure of the model in order to decrease the number of excel sheets the user has to operate.

8.2 The structure of the HIT model

The suggested structure of the HIT model is built with this thesis definition of TCO in mind, see section 3.3. The structure also looks like the earlier presented structure developed by Berglund and Ericsson, see section 4.2. In Figure 23 the structure of the developed HIT model can be seen.

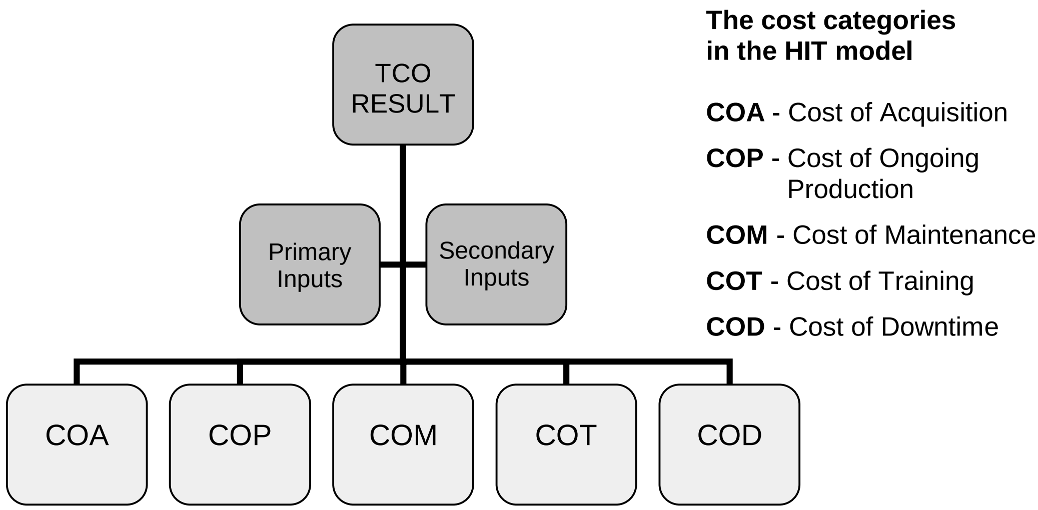

Figure 23 The structure used in the HIT model made in excel.

In order to increase user friendliness the HIT model consists of two input sheets, one result sheet and five calculating sheets. The input sheets are named primary inputs and secondary inputs and those are the only sheets where the user enters information. In addition to those sheets there are five calculating sheets that the user does not need to pay attention to. Those sheets contain the calculations for the costs of; acquisition (COA), ongoing production (COP), maintenance (COM), training (COT) and downtime (COD). Beyond this, one sheet presents the results of the analysis by using diagrams showing the impact of the different costs. Hence, the user is only supposed to use the thirst three sheets of the model, the ones dark shaded in Figure 23.

The suggested structure is similar to the structure developed by Berglund and Ericsson but it is expanded with the category COT while cost of disposal (CVOD) and the cost of ownership (CO) have been excluded as main-categories. The reason for the additional COT and the excluded CVOD will be explained further on. The category CO is excluded because there is no use for a summarising category in the HIT model.

8.3 Primary and secondary inputs

One of the objectives of this thesis was to investigate what cost elements have the highest impact on TCO in order to decrease complexity and secure that effort is put on collecting the right data. The user of the HIT model can choose how detailed the model should be filled out. If input is only filled into the first sheets, i.e. primary inputs, only cost elements that contribute to five percent or more of the total TCO value are included. If the user wants and has the possibility to fill in more detailed information, the secondary input sheet can be used.

The decision of making the cost elements that has an impact of 5 % or more, to primary inputs is partly based on Activity Based Costing, see section 3.2.1. In this section it is stated that activities that use less than 5 % of an individual's resource capacity are often ignored. When considering the brewery case study and the contribution every cost element makes up, the limit of 5 % for what is called primary inputs is suitable. In Figure 24 it can be seen that seven cost elements have a much higher impact on the TCO analysis in the brewery case study than the rest of the cost elements. The seven elements with highest impact make up to 90 % of the total cost. The remaining 10 % consist of many small elements, where every each of them have an own impact of between 0-3 % on the TCO analysis.

The primary input sheet also contains a section of "common" variables, i.e. variables that are used in the calculation of several cost elements.

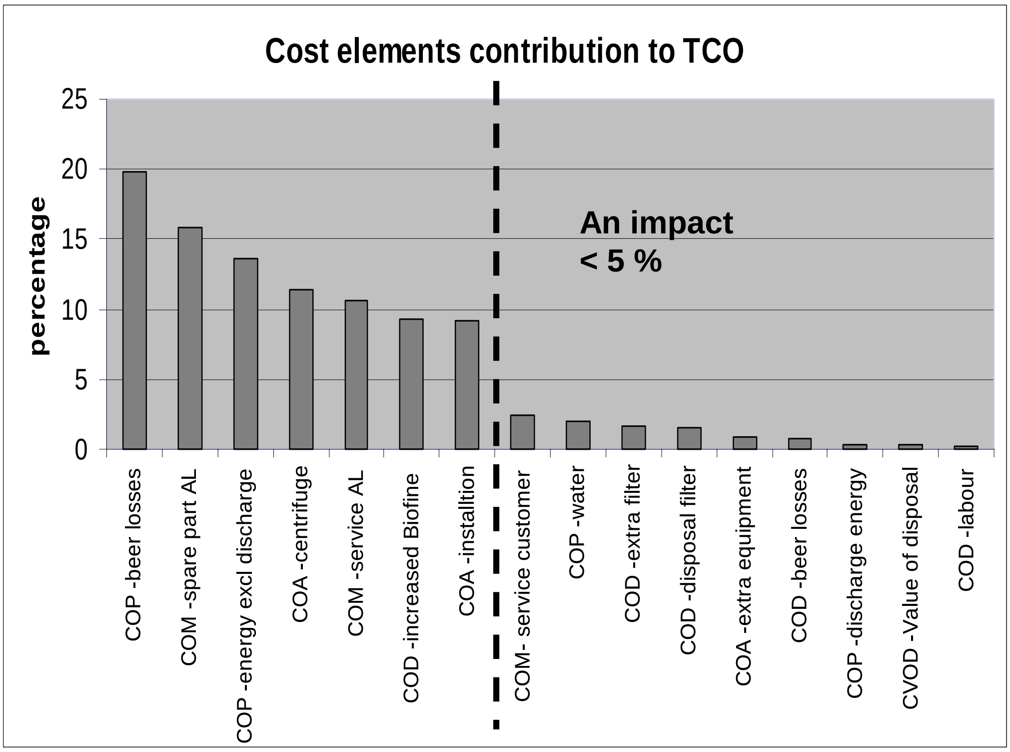

Figure 24 The contribution of every cost element in the brewery case study

When taking a look at what cost elements that are categorised as primary inputs it can be seen that the percentages not included are taken from all the cost categories, see Figure 25. It is only the cost element cost/value of disposal that does not exists on the primary input sheet.

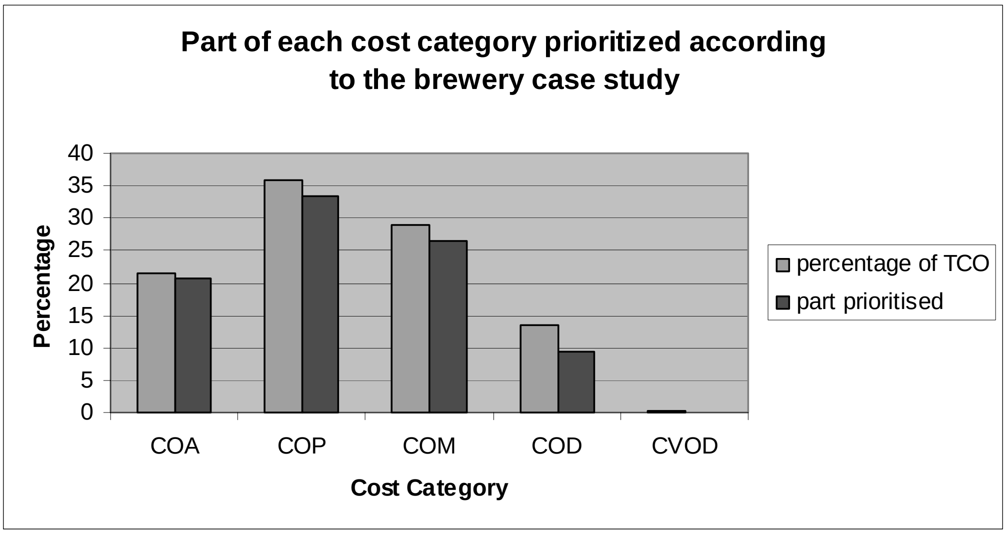

Figure 25 shows how big parts of the different cost categories that are calculated from the variables filled into the priority input sheet in the HIT model. The black piles in the figure represent the 90 % prioritised cost elements.

Of the 10 % costs that are too small to be included on the primary sheet, only the ones with an impact value over 1 % are included on the secondary input sheet. This is because the effort to get hold of the inputs needed is estimated to be much higher than the actual impact the information make. Of course those inputs could be estimated instead, but in the HIT model they are left aside in favour for making the model more user-friendly and less complicated. If the user of the model feels a need for adding extra costs into the model, there is a possibility to fill them in on the primary input sheet under the label other significant costs.

The presented shares of the cost elements above are taken from the brewery case study. A less detailed study was though also performed on the vegetable oil application and different cost elements' shares of impact on the TCO can be seen in Figure 26. In this diagram only five cost elements reach an impact level over five percent on TCO. The aggregated impact of those five elements is 89 percents on the total TCO.

Four cost elements that have a higher impact on the TCO in the vegetable oil study also have a higher impact in the brewery study. Those are; COA -centrifuge, COP -energy (excl discharges), COM -spare part AL, and COM -service AL. The three additional cost elements with a high impact on TCO in the brewery study; COP -beer losses, COD -increased biofine and COA –installation, has a low or no impact in the vegetable oil study. Instead COP –gas has a high impact in the vegetable oil application.

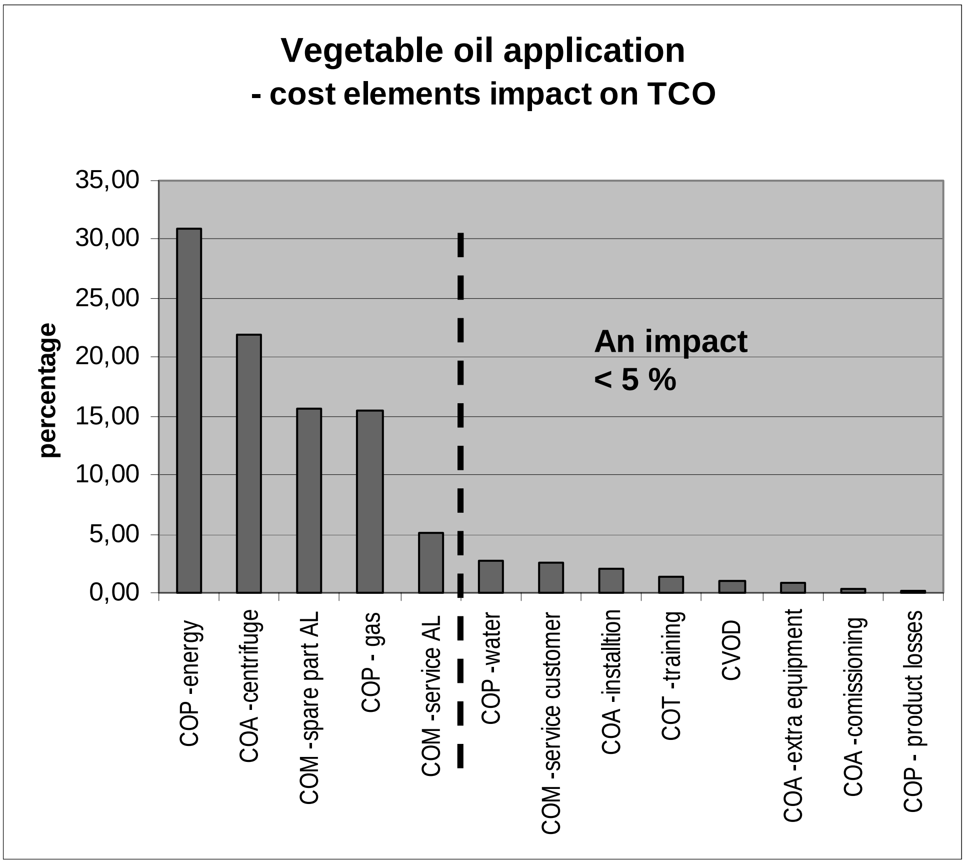

Figure 26 The contribution of every cost element in the vegetable oil study.

8.4 The impact of each cost category

As written in the discussion of issue, see section 1.2, it is of interest to improve the user friendliness of the model and to progress the model in a way that the number of needed input parameters will diminish. By prioritising the eight cost elements that have the greatest impact on the two studies described above, the number of input variables decreased significantly. Further on it will be described in more detail; cost elements included, cost elements left out and considerations that has been made in order to develop the HIT model into fulfilling all criteria stated.

8.4.1 Cost of Acquisition

Cost of acquisition counts for 22 % of TCO in the brewery case study and for 25 % of TCO in the vegetable oil application study.

Table 2

Cost elements from the Cost of Acquisition category					
	centrifuge	installation	extra equipment	commissioning	**Percent of total TCO**
Brewery case study	11 %	9 %	1 %	-	**21%**
Vegetable oil study	22 %	2 %	0,8 %	0,3 %	**25 %**

The cost of the centrifuge includes only the machine, therefore the input in the TCO calculation will be the unit price charged for the centrifuge. In the brewery case study the cost of the centrifuge is 11 % of TCO. In the vegetable oil study the cost of the centrifuge showed an impact of 22 %. Hence, it is regarded as a primary input in the HIT model.

Cost of additional equipments in the case studies counted for 0,8-1 percent of TCO. However, this cost is highly dependent on the type and the amount of additional equipment bought. To facilitate the usage of the HIT model, the cost of extra equipment can be pre-calculated in the model; therefore the needed invariables are the type and the amount of additional equipments. In the case studies the cost of extra equipment made a little impact on TCO and it is realistic to assume that this will be the case in other studies as well. Therefore the type and the amount of extra equipment are secondary inputs in the HIT model.

Costs of packaging and freight could not be specified through the case study. The cost was assumed to have rather low impact on TCO which is confirmed through an estimation made by Alfa Laval. When the estimated amount is compared to the other cost elements it makes an impact of less than one percent, therefore it is excluded from the HIT model.

In the case study the installation of the centrifuge was done by an external part, in such cases the cost of installation is known which enables the user to fill in the total amount of cost of installation. In the case study, installation cost is rather high and counts for nine percent of the total cost of ownership; the reason for this was the complexity of the installation at the specific site and mistakes during the installation. In the study of the vegetable oil application the impact of the installation cost was only two percent. Since installation cost can have a high impact on TCO depending on the specific circumstances at the production site it is a primary input in the HIT model. If cost of installation is not completed by the user of the HIT model an installation cost based on activities will be calculated. The cost of installation depends on the different tasks included in an installation of a centrifuge, such as electrical and mechanical installations. Therefore it is beneficial to use the logical concept of ABC when calculating or estimating cost of installation. The resources needed to the installation, such as human resources and materials are driven by the labour hours and amount of material needed. In the HIT model these are estimated and connected to the activities included in the installation. In this way the invariables can be limited to the hourly cost of labour.

The cost of acquisition can be calculated through filling in four invariables into the HIT model. The primary input variables are the cost of the centrifuge and, if it is possible to obtain, the total cost of the installation. Secondary invariables are the type and amount of extra equipment and the cost of labour.

8.4.2 Cost of Ongoing Production

Cost of ongoing production accounts for 35 % of TCO in the brewery case study and 50 % of TCO in the study of the vegetable oil application. Of the 35 % in the brewery study, 33 % are categorised to be included in the primary input sheet in the HIT model. Two of the COP elements; discharge energy and water, are not making a greater impact on TCO. The costs elements which have a countable impact are; energy (exclusive discharges), production losses, other supplies and gas in the vegetable oil application.

Table 3

Cost elements from the Cost of Ongoing Prodution category	energy excl discharge	product losses	gas	water	discharge energy	**Percent of total TCO**
Brewery case study	14 %	20 %	-	2 %	0,4 %	**35 %**
Vegetable oil study	31 %	0,2 %	15 %	3 %	-	**50 %**

Whether the total amount of energy is going to be included in the primary input sheet or not, depends on what cost drivers the user wants to put into the HIT model. In the case study the average current and the voltage were collected from the control system and the contribution of discharge energy was computed afterwards. When energy use is calculated in this way, the impact of the energy cost for discharges is too small to be included. It counts for less than one percent in the brewery application in the study. It then has an even smaller impact on the TCO on a centrifuge in the vegetable oil application. That is because the number of discharges is a lot smaller for a centrifuge in use in the vegetable oil application.

In a general view though, production sites can have a meter that record the total energy use for the whole centrifuge. In that case, the whole cost for energy used will be included in the TCO. The reason of that is that the cost driver *power* then will be used as an input, instead of the cost drivers *current level* and *voltage level*. In the HIT model, the user can choose what input variables to use for this calculation.

The COP -production losses is the cost element that has the greatest impact of all cost elements in the brewery case study, it accounts for 20 percent of TCO. In the brewery case study the lost beer was divided into; what kind of brand the beer had, and thereafter it was multiplied with the specific cost per hectolitre for every beer brand. This cost does not need to be calculated in great detail in the HIT model, the cost for producing different brands differs with ten percent and makes an impact of one percent in the TCO analysis. Because it only makes an impact on TCO with one percent, it is not possible to put in different losses with different costs in the HIT model. The cost for product loss is so small that it can be negligible in a study of a vegetable oil site. But it will nevertheless be a cost item that belongs to the primary input sheet because of the impact the cost element can have on other applications. It will though be commented and when the HIT model is used for the vegetable oil application, the inputs regarding this cost can be passed over.

The cost drivers for COP -production losses are; number of discharges, litre loss per discharge and cost per litre lost product. This is therefore the inputs that the user should enter into the HIT model. In an analysis regarding the vegetable oil application, this cost will have a much smaller impact due to that the centrifuge only discharge about once an hour. In the model, inputs to calculate production lost will be asked for on the primary input sheet but the user can choose to leave the information out if the contribution is approximated to be small.

The COP -consumable supplies include; water, gas and other supplies, whereof only water was included in the brewery case study. The COP-water made a small impact on the TCO and that is partly because the study was done on a site located in a part of the world where water costs are low. In other countries the cost can be higher but it will anyway not affect the TCO enough to be included in the sheet for primary inputs. The inputs to calculate the water cost are water used per discharge, number of discharges, water used per hour, number of production hours and water price. Both number of discharges and the number of production hours are though already entered into the HIT model they are e.g. used for calculating the energy cost. Water consumption is though tricky to approximate because different customers can use water in different ways. A user can decide to use more or less water during cleaning of the centrifuge and at some plants the water can be recirculated. But nevertheless the consumption of water has a low impact on the TCO and many measurements need to be done in order to find e.g. consumption per discharge. Therefore the inputs for the element COP –water belongs to the secondary input sheet in the HIT model.

An example of another supply that can be included in the model is a cleaning detergent. In the brewery case study it was not possible to attain the consumption of this chemical and therefore it was left out from the analysis. Nevertheless, other supplies are calculated on the primary input sheet because they could have a big impact on the analysis. Other supplies are driven by consumption and price.

The cost for gas, carbon dioxide in the brewery application, was not included in the brewery case study because the consumption and the cost for it were too small. This had to do with the fact that carbon dioxide is a rest product in the production of beer. In another application though, as the Table 3 shows, gas can be used to a higher extent. The gas used in different centrifuge applications can be carbon dioxide or nitrogen gas, and therefore the cost for the supply can differ a lot. This makes the consumption of gas and the gas price to input variables to fill in to the primary input sheet.

8.4.3 Cost of Maintenance

Cost of maintenance was complicated to obtain in the case study. To facilitate the usage of the HIT model and make it applicable for studies with lack of historical data the cost of maintenance can be estimated.

Cost of maintenance can be divided into preventive and corrective maintenance. The benefit from this breakdown is that preventive maintenance has been structured into activities. Preventive maintenance can be structured in activities that are performed according to operating hours e.g. every 2000 hour of operation change spare part X which requires service X, and activities that are performed on a time basis e.g. every second year change spare part Z which requires service Z.

The structuring of preventive maintenance into activities is beneficial since it enables a decrease in input variables. Each maintenance activity includes the cost of resources such as spare parts, service made by Alfa Laval and the customer maintenance employees needed to perform the maintenance. The cost of these activities is driven by the use of spare parts (cost of spare parts) and the time needed to perform the activity. These variables are pre-programmed and therefore the needed input variables are the hourly cost of a service engineer, the hourly cost of the customer labour employees and the operating hours per year. The activities are then programmed to be performed according to accumulated operating hours or on a yearly basis.

Regarding corrective maintenance it is realistic to assume that there will be breakdowns. The cost of corrective maintenance is highly dependent on specific circumstances at the site the TCO analysis concerns. A cost of corrective maintenance, estimated by Alfa Laval, is added to each year of operations. In the HIT model it will be 20 percent of the cost of preventive maintenance.

Cost of service performed by Alfa Laval makes an impact of eleven percent on TCO. Therefore the hourly cost of a service engineer is a primary input to the HIT model. Labour costs of production site maintenance employees made an impact of two percent in the case study. Therefore the hourly cost of production site maintenance employees is regarded as a secondary input. However one can argue that since the case study was performed in Latin America where labour cost is relatively low, the cost of production site maintenance labour might make a greater impact in a country where labour cost is higher. Sensitivity analysis showed that a 70 percent increase in labour costs will cause a five percent impact on TCO, other things being equal. It is realistic that the majority of costs will increase in a country with higher costs. Therefore it is assumed that the production site labour cost will remain making an impact less than five percent. In the study of the vegetable oil application which was made with European wages as inputs, the cost of production site maintenance labour represented three percent of TCO.

The cost of a service agreement will only make an impact when the customer has bought an agreement; therefore it has to be an invariable to the HIT model, since it can have a great impact on TCO it is a primary input.

The centrifuge does not require the customer to have more than one service kit in stock; therefore stock keeping cost has been excluded since it made an impact of less than one percent on the total cost. Logistical cost has been excluded from the HIT model since it is often included in the cost of spare parts and has a rather small impact on the total cost.

The cost of maintenance is calculated by five invariables whereof two are common invariables. The centrifuge lifespan, the yearly operating hours, hourly cost of a service engineer and the cost of a performance agreement are the primary inputs to the HIT model. Hourly labour cost of production site maintenance employees is a secondary input.

Table 4

Cost elements from the Cost of Maintenance category				**Percent**
	spare part AL	service AL	service customer	**of total TCO**
Brewery case study	16 %	11 %	2 %	**29 %**
Vegetable oil study	16 %	5 %	3 %	**24 %**

8.4.4 Cost of Training

Cost of training has been added as a cost category since training programs are often sold as a separate product. Cost of training is assumed to make a rather low impact on TCO depending on what programs the production sites request. When there is a recommended schedule for how often training should be performed the different training programs can be structured as activities. The cost of these activities depends highly on the number of participants that take part in each program. Therefore the number of participants is an input variable to the HIT model. Findings from the studies reveal that cost of training makes a low impact on TCO and therefore it is regarded as a secondary input.

8.4.5 Cost of Downtime

Cost of downtime is first of all driven by the actual downtime of the centrifuge and thereafter, it is of importance if the production has to be shut down or not while the centrifuge is down. Hence, if the site has other equipment to use and if the production has spare capacity. How the operator of the centrifuge choose to run the production varies between different applications but sometimes also between different organisations within the same application. Therefore the user of the tool has to fill into the HIT model if the production must be down when the centrifuge stops working and the capacity utilised in the production.

As discussed in section 3.1.2, it is important to take on a customer view and customers' invest in equipment to earn profit. Therefore, if centrifuge downtime is equal to production downtime and the capacity used in the production is 100 percent, the whole income loss because of lost production should be calculated as having an impact on the TCO. The cost is calculated as; units of lost production multiplied with the profit per unit. But if not all of the capacity is used, the user of the HIT model needs to decide if this cost should impact the TCO in this way or not, this decision has to be taken under consideration of the specific customer situation.

If the production can be running while the centrifuge is down the extra cost needed per production unit should have an impact on the TCO. As stated in the case study, there are a couple of costs that direct can be neglected because of their low impact. Those costs are the handling cost for the extra amount of filter used, the cost for the extra downtime because of more wear and tear of the filter equipment and the cost for extra water and cleaning needed.

Other cost affected by downtime are the cost of production lost per filter recharge and cost of extra man-hours needed to exchange the filter which both are driven by the amount of recharges. Therefore those costs could be looked at as being one cost per number of filter recharges. These costs though acquire three inputs; two costs and one number of recharges. This is not information that is easy to obtain or approximate and the impact of each cost element is less than one percent. Therefore those two cost elements are excluded from the HIT model.

The cost elements of; extra amount of filter used and the disposal of the filter, are driven of the extra amount of filter needed (approximated with a percentage), the cost of filter and the cost of disposal of filter. Those inputs are entered into the secondary input sheet because of the small impact the number makes up.

The cost of biofine was quite high in the brewery study. This chemical is though forbidden at the present time in the country where the brewery is situated, so it is not used anymore at that site and probably not on other sites either. It is therefore no room in the HIT model to calculate this cost under the cost category downtime. If the user of the model know that the there is an additional specific high cost for the centrifuge in the process it is in, there is a possibility to enter this information into the HIT model under the title other significant costs on the primary input sheet.

Table 5

Cost elements from the Cost of Downtime category						
	increased chemical (biofine)	extra filter	disposal filter	product losses	labour	**Percent of total TCO**
Brewery case study	9 %	2	2 %	0,7 %	0,2 %	**14 %**
Vegetable oil study	-	-	-	-	-	**0 %**

8.4.6 Cost of Disposal

Cost of disposal was excluded in the ABI model developed by Berglund and Ericsson. In the case study of the brewery application and the study of the vegetable oil application cost of disposal is a value since the centrifuge is sold when the lifetime is over. This value is less than one percent of the TCO. Centrifuges most often have both a cost and revenue of disposal and these are often so small that they level off each other. Since this cost category made an impact on less than one percent on TCO it has been excluded from the HIT model.

8.5 Verification of the HIT model

The HIT model was tested with values from the brewery case study and the values generated by pre-programmed activities. The result of the calculated TCO value achieved can be seen in Figure 27. The HIT model calculated a TCO value that was 19 percent lower than the calculated value in the case study. The reason why the value differs is because the cost of maintenance (COM) is much higher in the case study than it should have been in a more general setting, which can be seen in Figure 28. Above all, corrective maintenance costs were higher in the case study than they are estimated to be in the HIT model. These costs are a result of that the chosen model of centrifuge at the brewery is not compatible with the production process at the brewery. The tearing process has caused damages on certain spare parts and resulted in high corrective maintenance costs. One can argue that the percent of corrective maintenance costs should be higher. However it will not reflect a normal situation where the centrifuge is compatible with the production process.

The impact of cost of downtime (COD) is also higher in the case study TCO and this is because of the increased use and cost of the chemical biofine during downtime. This cost will not exist in other studies and therefore it has been removed from the downtime cost category and instead it has been added as an extra specific cost (called Extra cost in the diagrams). The cost of disposal (CVOD) is a cost category that was included in the case study but it has been neglected in the HIT model because of its small impact. Cost of training (COT) on the other hand is not included in the case study because the information could not be attained, but it will make a small contribution in the HIT model.

The cost of ongoing production (COP) is the same size in both of the calculations. This is because the exact values were added in the HIT model. Hence, the calculation of this cost category in the model does not contain any general assumptions. The reason for this is that those numbers will differ a lot depending on the production site, and how the organisation chooses to use the centrifuge.

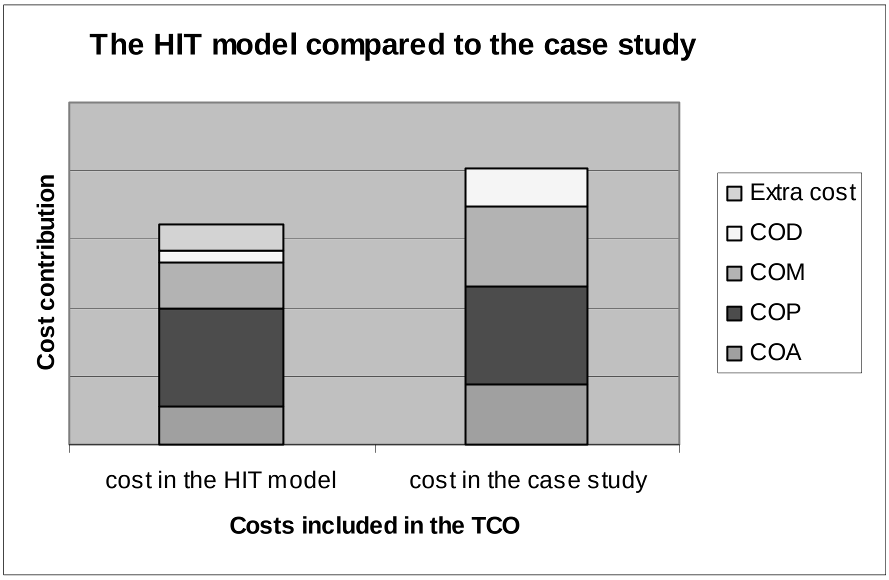

Figure 27 The cost of TCO calculated in the HIT model is 19 % smaller than the actual cost calculated in the brewery case study. CVOD and COT is excluded in the diagram because their impacts are too small to be visible in the diagram.

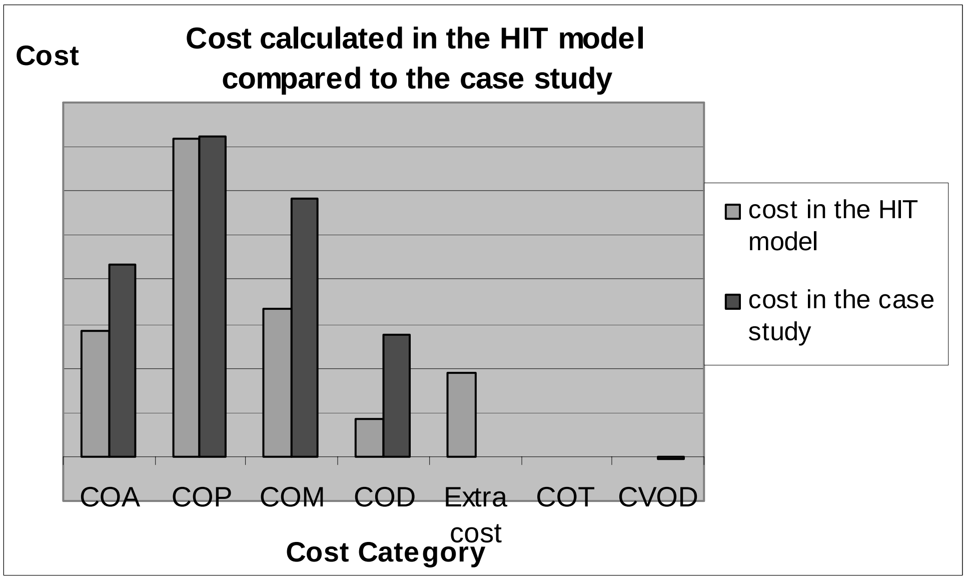

Figure 28 The impact on the TCO of the different cost categories, in the HIT model compared to in the brewery case study.

A difference with 19 percent is reasonable when taking into account the exceptionally high maintenance and installation costs that was the reality in the case study.

To make the HIT model more accurate it needs to be verified and tested with more case studies. If there is a need for good estimations made by the model when inputs are missing, a data base with general consumption numbers for different centrifuges needs to be added to the model. In that way a number for the consumption of different inputs with high accuracy could be suggested, when giving some critical data as; model of centrifuge and production per hour. Those numbers have not been possible to collect in this thesis when the detailed input mainly came from one specific study.

8.6 TCO analysis of customer equipment – Blueprint

TCO calculations are often made on equipment used within the organisation, not often are they made on customers equipment. Therefore articles about the concept mainly describe the procedure of TCO analysis on equipment used within the organisation. As described earlier there are many situations when it is interesting to do a TCO calculation of equipment used by a customer. The inputs to the calculation are the same but the procedure needs to hold a slightly different approach.

1. *Secure interest in TCO.*
   There must be an interest for a TCO calculation, both from the organisation performing the analysis as well as from the customer. The driving forces for performing the analysis should be apparent for all participants.

2. *Give someone the responsibility for the project.*
   One employee from each organisation needs to be responsible for the project. These employees need to have a network of people within their own organisation who can contribute with important expertise and information to the TCO calculation.

3. *Identify relevant costs to include in the analysis.*
   During the identification of relevant costs, it facilitates if the structure suggested in section 8.2 is applied.
   - Elements to include in cost of acquisition are often similar among organisations and hence can be captured from the suggested structure.
   - Elements to include in cost of ongoing production have to be discussed with the process where the centrifuge is going to be integrated in mind. Therefore a visit at the customer site is necessary. The elements to include are those with the highest impact on production costs.
   - Elements to include in cost of downtime have to be discussed with the process in mind; the cost will vary depending on if there is an alternative process.
   - Elements to include in cost of maintenance are most easily identified with the necessary maintenance activities in mind.

- Elements to include in cost of disposal depend on the strategy of the customer and hence should be discussed with the customer.

4. *Develop/ adapt a TCO excel model.*
   With all the elements to include in mind it is time to develop a TCO model for calculations. If there is an existing model it might need to be adapted to the specific customer depending on the requirements of accuracy.

5. *Collect information about identified cost elements.*
   This part is the most time consuming part of the project. It is crucial to identify contact people that can provide information about each element. Then information can be collected through grouping elements depending on contact person. If information is not measured it has to be discussed whether to measure information or to make assumptions. It is of great importance to keep records of the data resources and note if there is information not available or usable, and if there is information based on assumptions.

6. *Make the calculation.*
   Involves entering the cost information into the TCO model, it could be an advantage to perform this step while the information is collected.

7. *Analyse the result.*
   First of all, is the result plausible? If not, either the calculation or the information data might be wrong. To confirm the impact of certain elements it is of interest to do a sensitivity analysis.

8. *Document experience from the working process.*
   In order to secure that valuable experience about TCO analyses is not lost it is of importance to document the working process and challenges.

9 Conclusions

This chapter aims to summarise the findings and conclusions from this thesis in order to accomplish the objectives of the thesis.

9.1 Findings

The HIT model for TCO calculations has been developed. In order to increase user-friendliness the general tool developed consists of two input sheets, one result sheet and five calculating sheets. The tool has been developed in a way that makes it applicable when there is lack of historical data. This is done through structuring part of cost of acquisition and cost of maintenance into activities, and by making the cost of ongoing production and the cost of downtime dependent on a limited number of inputs which can be estimated.

Findings from the case studies showed that seven cost elements contributed to 90 % of TCO in the brewery case, and that five cost elements contributed to 89% of the cost elements in the vegetable oil case. The rest of the cost elements made an impact of less than 5 % each, while some of them made an impact of less than 1 %. The cost elements that made an impact on less than 1 % have been excluded in order to secure that the user of the tool puts effort in collecting data regarding the elements that have a greater impact on TCO.

The input variables needed to calculate the cost elements that together caused an impact of 89-90 % in the both studies were added as primary invariables. Some of these are common invariables, i.e. used for several calculations. The input variables needed for calculating elements with an impact on less than 5 %, but more than 1 %, were added as secondary invariables.

The cost of acquisition is calculated through filling in five invariables into the tool. The primary variables are the cost of the centrifuge and, if it is possible to obtain, the total cost of the installation. Secondary invariables are the type and amount of extra equipment and the cost of labour.

The cost of ongoing production requires at most eleven invariables to be added into the primary sheet to calculate cost for energy, production losses, gas consumption and cost for other supplies. Two of those; production hours and number of discharges, are common invariables. The inputs to calculate water can be filled into the secondary input sheet and then three additional inputs are requested.

The cost of maintenance is calculated by five invariables whereof two are common invariables. The yearly operating hours, centrifuge lifespan, hourly cost of a service engineer and the cost of a performance agreement are the primary inputs to the tool. Hourly labour cost of production site maintenance employees is a secondary input.

Cost of training has been added as a cost category. The number of participants is an input variable to the tool. Since it is expected to have low impact on TCO it is regarded as a secondary input.

To calculate the cost of downtime, two common invariables and one or two extra invariables needs to be added on the primary input sheet. Additional, on the secondary sheet three inputs can be filled in. How many needed inputs on the first sheet depend on the answer of the question; can the rest of the production keep working when the centrifuge is down?

The impact of cost of disposal is too small to make a large impact. Therefore the cost category has been excluded from the tool.

In total 17-19 invariables needs to be entered into the tool to calculate the cost elements that in the brewery case study had an impact of 90 percent of TCO. Eleven additional invariables is needed to calculate the costs on the secondary input sheet of the tool.

The tool was verified through using the information retrieved from the brewery case study as invariables to the tool and comparing the result with the result from the case study. The tool calculated a TCO that was 19 percent lower than the result from the case study. The difference is mainly caused by high corrective maintenance cost in the case study. Because maintenance cost is built up in the HIT model with help of general numbers for when activities are performs, those general numbers were used.

When developing a tool for calculating TCO there is a trade-off between the extent to which the tool can be generally applied and the accuracy of the result the tool will provide. We believe that it is not possible to make a tool applicable for all Alfa Laval centrifuges; it is more suitable to make modifications of the tool for each application. It is also important that the tool considers differences between different models of centrifuges within the same application. The HIT model is developed for a centrifuge within the brewery application and a centrifuge within the vegetable oil application. However the structure of the HIT model is useful for other application as well and the model can be updated with information in order to be applicable for other models of centrifuges. Customer’s processes can look different within the same application; therefore it is of great importance to make a TCO calculation with the customer‘s process in mind.

9.2 Further research

- It is of interest to further test the HIT model in order to verify the model.
- More TCO studies of other industries would be interesting to see if there are great differences or if the relative impact of cost categories is almost the same.

- More TCO studies of organisations within the same industry are of interest to see if there are great differences within the same industry.

- It is of interest to conduct more studies about how downtime and availability affects profit.

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